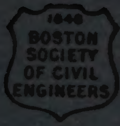
# JOURNAL OF THE BOSTON SOCIETY OF CIVIL ENGINEERS



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Volume XXI JANUARY, 1934 Number 1

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JOURNAL OF THE

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Volume XXI JANUARY, 1934 Number 1

# NEW TYPE OPEN-NOZZLE FOR MEASUREMENT OF SEWAGE FLOW

By Karl R. Kennison, Member*

(Presented at a meeting of the Sanitary Section of the Boston Society of Civil Engineers held on December 6, 1933)

The Metropolitan District Water Supply Commission was authorized by chapter 262 of the Acts of 1932 to construct a main sewer for the purpose of maintaining and protecting the purity of the water supplied from the Wachusett, Quinapoxet and Ware river areas to the Metropolitan Water District and the city of Worcester. This work is incidental to the new development of the Ware River watershed as a source of water supply for the Metropolitan District.

## Sources of Sewage to be Diverted

This sewer extends 48,465 feet from the neighborhood of Rutland Center in a general southeasterly direction through Rutland and through or near the villages of Eagleville and Holden Center in the town of Holden to a point at the boundary line between Holden and Worcester alongside the state highway leading from Worcester to Holden. There it connects with a main sewer, which by authorization of the same act the city of Worcester has constructed within its city limits as a part of its main trunk sewer system tributary to its sewage disposal works. The location of this Rutland–Holden sewer is shown on the Locality Plan, Fig. 1.

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* Designing Engineer, Metropolitan District Water Supply Commission, 20 Somerset Street, Boston, Mass.

The two principal sources of the sewage which will be diverted immediately upon completion of the construction are the Rutland State Sanatorium and the United States Veterans Hospital, both in the town of Rutland. The State Sanatorium is located within the Wachusett watershed, and a system of sewers collects the sewage and carries it across the divide to filter beds in the upper Ware watershed area. These beds were constructed about 1897 and are inadequate to take care of present needs satisfactorily. The United States Veterans Hospital is situated in the Ware watershed area, and a system of sewers collects the sewage and discharges it on to filter beds, constructed in 1924, close to a brook tributary to one of the small ponds in the upper Ware watershed area. The construction of the Rutland–Holden sewer will eliminate both of these sewage filter beds, and both the state and the Federal

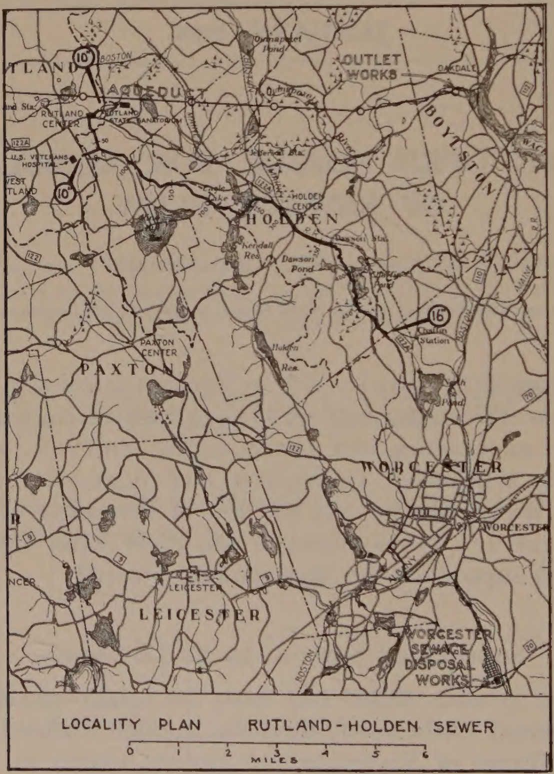

Fig. 1. — Locality Plan

authorities are co-operating in the construction and maintenance of the new line.

A 10-inch line is being laid from a point of connection with the existing sewer at the State Sanatorium, a distance of 5,120 feet to the junction point with a 10-inch branch 1,745 feet long from the property line of the United States Veterans Hospital grounds, to which line the Veterans Bureau will construct a short length of sewer from their existing collecting system.

From this junction of the two 10-inch branches a 12-inch pipe is being laid a distance of 20,585 feet to a point on Main Street in Holden, at which point allowance has been made for a possible future connection to divert sewage and industrial wastes in that vicinity.

At this point the size of the pipe is increased from 12 inches to 16 inches and continues a distance of 22,760 feet to the Holden–Worcester line, from which point southerly the city of Worcester has already completed a connecting link into their system of trunk sewers.

## Apportionment of Cost

An agreement with the city of Worcester includes compensation for the construction of the necessary connecting link within the city limits and payment of a fixed sum for the right to use the city's sewerage system and treatment plant. It also includes an annual payment for the cost of cleaning and repairing the sanitary sewers of the city and operating the sewage treatment plant. This annual cost will be the district's proportionate share computed in the ratio which the quantity of sewage discharged at the Holden–Worcester line bears to the total quantity of the sewage treated by the city at its treatment plant.

## Cast-Iron Pipe Used

On account of this arrangement for payment in proportion to the quantity of sewage, it is important that this line be as tight as possible to prevent seepage of ground water into the line. It is also important that the line be as tight as possible to prevent escape of the sewage into the Wachusett watershed, the purpose of the entire construction being to protect the purity of the water supply. On this account, those portions of the line near the actual water courses and laid on fills across these water courses would have been built of cast iron in any event. Preliminary estimates indicated that it would cost but very little more to construct the entire line of light-weight cast-iron pipe than it would to build of vitrified clay those portions of the line which were not laid alongside existing water courses. Accordingly, it was decided to use cast-iron pipe throughout.

The pipe used is centrifugally cast pipe in 16-foot lengths with barrel thicknesses of .42, .46 and .53 inches in the case of the 10-inch, 12-inch and 16-inch pipe, respectively. The actual inside diameters are 10.26, 12.28 and 16.34 inches, respectively.

## LENGTH AND SLOPES

The total length of line, including manholes, is 50,210 feet. There are 129 manholes in the entire line. The average distance between manholes is about 390 feet. The manholes are constructed of concrete against steel forms, and the covers are provided with a specially designed locking clamp. There are several places along the line where there is ample drop in elevation, yet there are many long stretches where there is no more than sufficient grade to maintain the velocity of flow. There are four places, namely, at the crossing of Worcester Brook, Asnebumskit Brook, Eagle Lake and a brook near Newell Road, where the pipe is being laid over culverts and on fills in order to maintain the grade without resort to siphons. The minimum grades used in the design of the sewer are shown in the following table:

| Nominal Diameter | Actual Diameter | Slope | Part Full | CAPACITY ($n = .015$) | | |
|---|---|---|---|---|---|---|
| | | | | f. p. s. | c. f. s. | m. g. d. |
| 10 | 10.26 | .00425 | .50 | 2.0 | .57 | .37 |
| 12 | 12.28 | .00310 | .50 | 2.0 | .82 | .53 |
| 16 | 16.34 | .00180 | .55 | 2.0 | 1.64 | 1.06 |
| Normal expected peak flows | | | .60 | 2.1 | 1.91 | 1.23 |

It will be necessary to measure the flow continuously at three points: first, at the point where the sewer of the Rutland State Sanatorium discharges into the 10-inch line; second, where the United States Veterans Hospital sewer discharges into the 10-inch branch; and third, where the main line discharges into the Worcester trunk sewer.

## DEVELOPMENT OF OPEN-NOZZLE FOR MEASUREMENT

The Commission has developed for installation at these three points a new type of measuring weir referred to as an open-nozzle, which will measure the rate of discharge with little loss of head and which will pass dirt and trash with a minimum of clogging. This has been called an open-nozzle because it bears the same relation to a nozzle that an open Venturi does to a Venturi. There is no opportunity for solids to settle out and require cleaning as would be the case behind an ordinary weir. In fact, there is practically no retardation of velocity, but only an increase of velocity in a very short length just upstream from the open-nozzle.

It can best be described and the method of its design best be explained by comparing its characteristics with what would be obtained if the sewage were simply allowed to flow freely from an open end of the pipe. It would be entirely feasible to use the free flow from a pipe end, and to determine the relation between rate of flow and the depth at a piezometer ring located at any convenient distance upstream from the end of the pipe. In such a case, however, the velocity would increase gradually, commencing a considerable distance back from the end of the pipe, and, even under conditions of maximum flow with the sewer practically full, the normal depth could not be maintained close to the end of the pipe; for example, in the case of the 10-inch pipe a flow which would practically fill the pipe in ordinary stretches would be running only about two-thirds full. This difference between the open-nozzle and the plain open pipe end is not very marked in the case of the 10-inch pipe because, in the case of sewers designed to maintain a minimum velocity, the velocity head is always relatively greater in proportion to the dimensions of the pipe in the smaller pipes of the line than it is in the case of the larger pipes. In other words, the normal flow, although it does not approach closely the condition of free-end discharge, is always much nearer to it in the smaller sizes of pipe than in the larger sizes. In the case of our 16-inch pipe a flow which would fill ordinary stretches of the pipe would be running not much more than half full in the case of free-end discharge.

As a result, any rating curve of the relation between discharge and depth above a plain open pipe end might be referred to as a flat curve; that is, each increment of discharge would register too small an increase in depth for the best measurement. Of course, this could be overcome by locating the piezometer ring a considerable distance upstream from the free-end discharge, but if this were done a possibility of clogging by deposition of solids in the bottom of the pipe in the long length between piezometer ring and the free end would be introduced.

The open-nozzle is simply an open pipe end which has been contracted in just the right amount and manner so that the normal flow in the pipe is not disturbed until just at the end of the pipe. In other words, there is no increase of velocity which would decrease the depth and result in an unsatisfactory flat rating curve. Neither is there any reduction in velocity the same as would be the case back of a V-notch weir, for example, which would result in deposition of solids requiring constant attention to cleaning.

## Characteristics of this New Type Weir

The characteristics of this new type weir are illustrated on a graph which shows in the case of both the 10-inch and 16-inch open-nozzles:

A. The normal energy gradient representing the condition of flow at the specified slope in normal stretches of the pipe, neglecting the open-end discharge.

B. The energy gradient with throttling effect of the contraction at the nozzle end, computed without considering the uncertainties due to the fact that the stream lines depart from the horizontal plane near the nozzle end, and that the free vent to atmospheric pressure under the jet is felt some little distance back from the nozzle end. In other words, this gradient is the theoretical gradient, assuming the pressure is proportional to the depth below the surface.

C. The true energy gradient at the piezometer ring, the difference between B and C being that determined by experimental tests to be due to the uncertainties introduced by the fact that the pressure at the critical section at the nozzle end is, as stated above, not proportional to the depth below the surface. Of course, this difference from the theoretical gradient also includes any very slight differences between the dimensions of the castings as actually made and those called for in the pattern, due to smoothing down of metal surface irregularities, etc.

D. The minimum energy gradient neglecting the throttling effect of the nozzle end contraction; in other words, the gradient corresponding to the critical stage of flow in the circular section.

E. The rating curve, the vertical difference between C and E being the velocity head.

F. The lower alternative stage of flow with the energy content C, the rating curve E being the upper alternative stage.

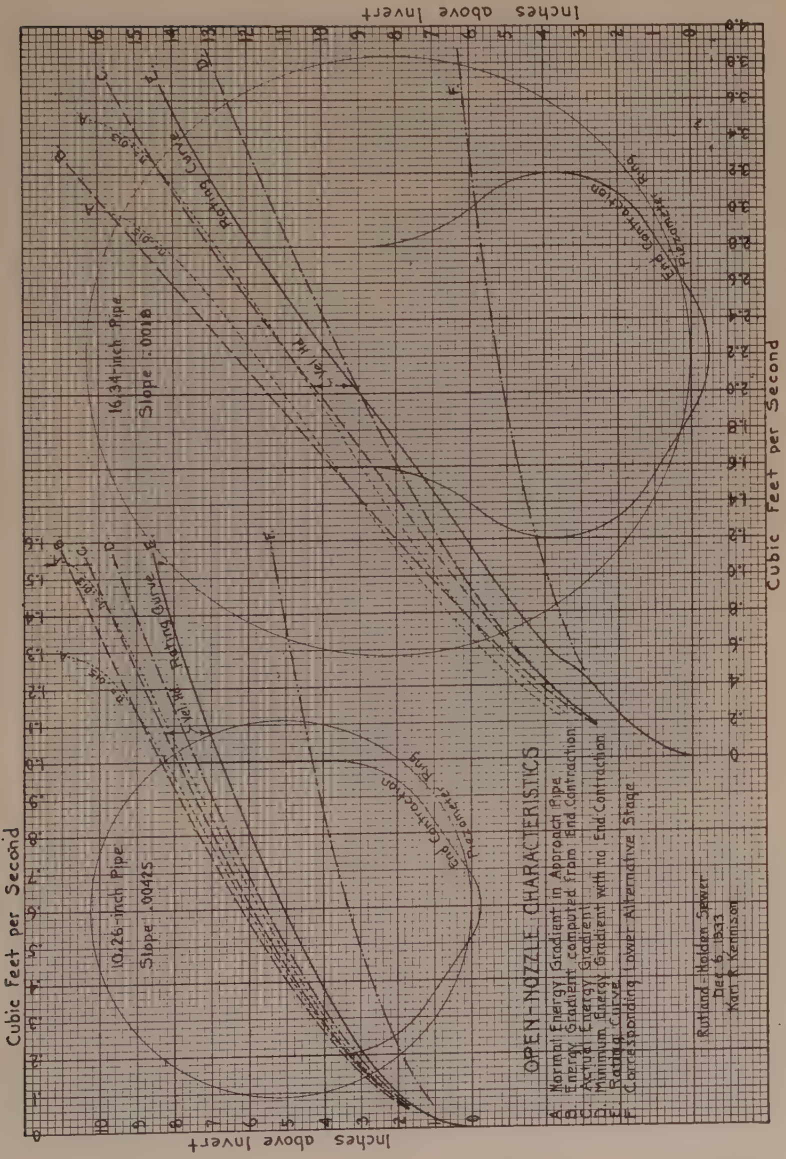

FIG. 2. — OPEN-NOZZLE CHARACTERISTICS

## PRINCIPAL CONSIDERATIONS IN DESIGN

The principal considerations involved in the design expressed in terms of these graphs are:

(1) To so contract the nozzle end that curve C is not materially higher than A. Otherwise there will be a slowing down of the velocity and a tendency to deposit solids.

(2) To have sufficient contraction in the lower portions of the nozzle end so that C will not approach too close to D within the range of flows with which we are particularly concerned in any given nozzle, or, what amounts to the same thing, to see that curves E and F are not too close together. Otherwise the water surface at the piezometer section will not be as sharply determined as it otherwise might be on account of a possible slight tendency to surface waves. Also the rating of the nozzle would not be independent of the approach slope of the pipe. This consideration was particularly important in the two 10-inch nozzles where it is expected very low flows will be of frequent occurrence and require accurate measurement, and where there may be some variation in the slope of the energy gradient, if not of the pipe itself, approaching the nozzle, on account of the nearness to the point of discharge from the hospitals into the sewer.

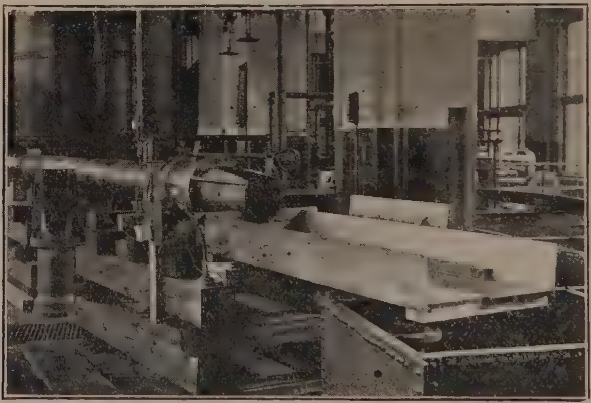

FIG. 3. — 10-INCH NOZZLE

In the case of the 10-inch nozzles, curves E and F are so far apart that in order for any given rate of discharge to follow the lower alternative stage, or curve F, the approach slope would have to be from about

17 to 26 feet per thousand (corresponding to a roughness coefficient of $n = .013$ to $.015$). Hence it is impossible that the sewage could ever be fed into the line at a sufficiently high rate to maintain such high velocity flow to the nozzle and upset the rating.

In the case of the large 16-inch weir, however, the approach slope is rather flat and is fixed for a long distance upstream. Incidentally, at the end of this seven-mile trunk line the more important flows to consider are not the very low flows. In the case of this 16-inch weir, although the curves E and F approach and intersect, there will be no variation in the slope of the approach pipe, and it was possible by exercising sufficient care in the laboratory tests to obtain an accurate rating curve for these occasional low flows, even though the lower alternative stage prevails at the lowest flows and a tendency to surface waves is apparent in the transition to the upper stage. It was necessary to accept these irregularities in the case of the relatively unimportant low flows in the 16-inch nozzle at the lower end of the trunk line in order —

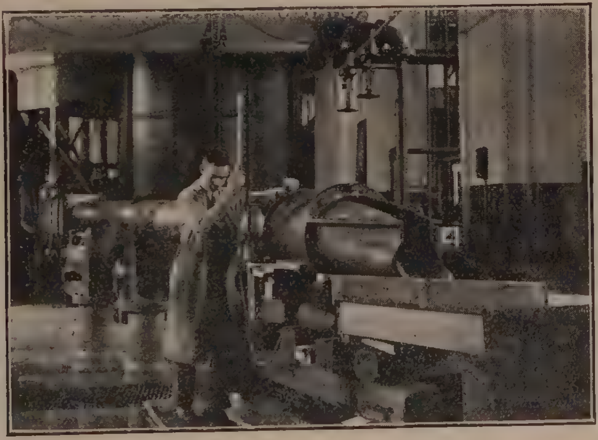

FIG. 4. — 16-INCH NOZZLE UNDER TEST

(3) To limit the amount of the contraction so that there will be no clogging with large solids, and at the same time to see that the variation of the contraction with depth is such that the resulting rating curve is not flat, but, in the interest of precise measurement, is as steep as possible; that is, to see that curve E is, at the right of the chart, as high as consideration (1) above will allow. There is a marked difference in this respect between a large and a small nozzle, for example the 16-inch and 10-inch nozzles, in a line designed for uniform scouring velocity in

the different sizes, on account of the fact that the relation between the normal velocity head and the diameter of the pipe is so different in the two nozzles. It is this difference which gives the 10-inch nozzle such a different appearance from the 16-inch nozzle. As to freedom from clogging by large solids, the 10-inch nozzle will pass an 8-inch sphere, and the 16-inch nozzle will pass a sphere about 8.8 inches in diameter. To shape the 16-inch nozzle so as to avoid clogging and to secure a steep rating curve made it necessary to accept the relatively unimportant irregularities in the case of the low flows referred to above. As to steepness of the rating curve, the 10-inch shows about 4 to 5 inches rise for an increment of 1 cubic foot per second, and the 16-inch, in spite of the difficulties referred to above, about 3½ inches.

(4) To make the parts easily accessible for cleaning and repairing if necessary. Both nozzles have a wide slit in the top through which they can be swept clean at any time. As to freedom from clogging compared with the Venturi meter, note that the throat diameter of a Venturi meter used in place of the 10-inch open-nozzle would have to be about 3 inches in diameter, and in place of the 16-inch open-nozzle about 4½ inches.

## Castings

As to the practical application in working out the details, each nozzle consists of two castings. One of these is intended to be imbedded in the wall of the measuring station and has a bell end to take the sewer pipe approaching the nozzle. A piezometer connection is tapped into the invert of this pipe near its downstream end. This consists of a three-fourths-inch brass pipe accurately fitted to the curve of the invert with clean sharp corners and firmly locked with an iron lock nut to prevent any movement. This length of pipe was not allowed to project to such an extent that it could be damaged by rolling the pipe in handling. This short straight length of pipe enters the top of an intermediate chamber consisting of a 3-inch pipe arranged for convenient blowing off and cleaning. Another small piezometer pipe runs from the top of this blow-off chamber to a 16-inch pipe well in which a float operates to actuate the recording gage mechanism.

The other casting in each case is bolted to the piezometer casting, and gives a smooth gradual transition between the round pipe and the carefully designed end contraction. There are two projecting horizontal fins, one on each side of this nozzle, which support accurately prepared surfaces for setting the nozzle at the predetermined grade and for checking the continued accuracy of such setting.

The patterns were inspected before the castings were allowed to be poured, a smooth surface on the castings was required, free from scale, lumps, blisters, sand holes and defects of every nature. This surface was thoroughly cleaned and smoothed, but no machine work was required other than the facing and drilling of the flange connection. The castings were painted after inspection and before rating in the laboratory.

The author of this paper does not intend it to be a dedication to the public of possible patentable material.

# A COMPARISON OF STEAM PILE HAMMERS

By Chas. W. Robinson, Member*

Before starting the foundation piling for the George Eastman Research Laboratories of the Massachusetts Institute of Technology, wash borings were made and test piles driven to determine the top, thickness and resistance to pile driving of the sand stratum.

A double-acting steam hammer was used for part of this preliminary work. The ram weight was 1,500 pounds, and the stroke was 16 inches. It took considerable time to drive a 50-foot pile through the miscellaneous fill, silt, sand and clay, and a serious reduction in steam pressure took place during the interval of driving. The number of blows of the ram decreased from about 140 per minute at the start to about 106 at the finish. This was equivalent to nearly a 50 per cent loss of energy in foot pounds. (See Fig. 1.) Because of the fluctuation, which was not uniform, it was difficult to tell just when the pile reached

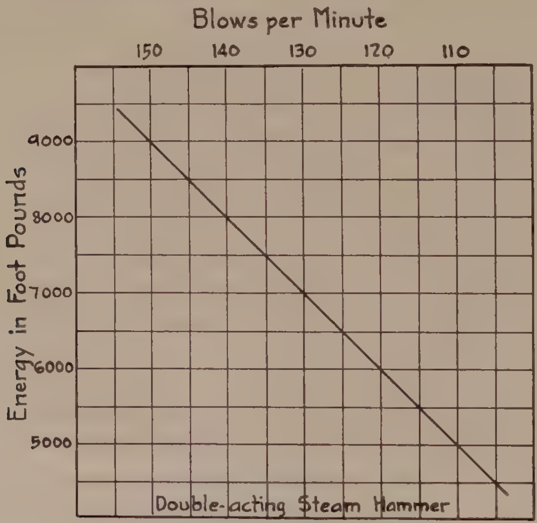

CHART SHOWING DECREASE IN ENERGY WITH BLOWS OF RAM PER MINUTE

FIG. 1

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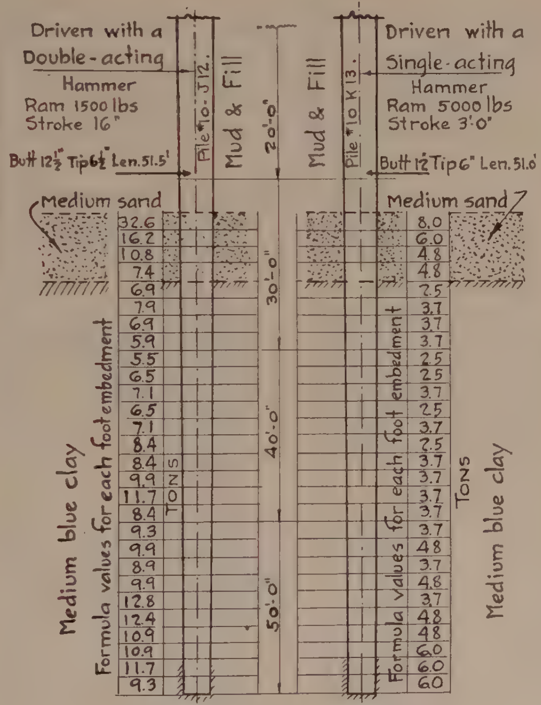
* Engineer and Field Representative of Chas. T. Main, Inc., Structural Division.

the sand or when it broke through the bottom of the stratum and entered the clay.

It was necessary to keep a record of the blows per minute as well as the blows per foot of penetration of the pile into the soil. This made it necessary to have two inspectors at the driver during the driving.



Comparison of Hammers
Two Piles in Similar Soils

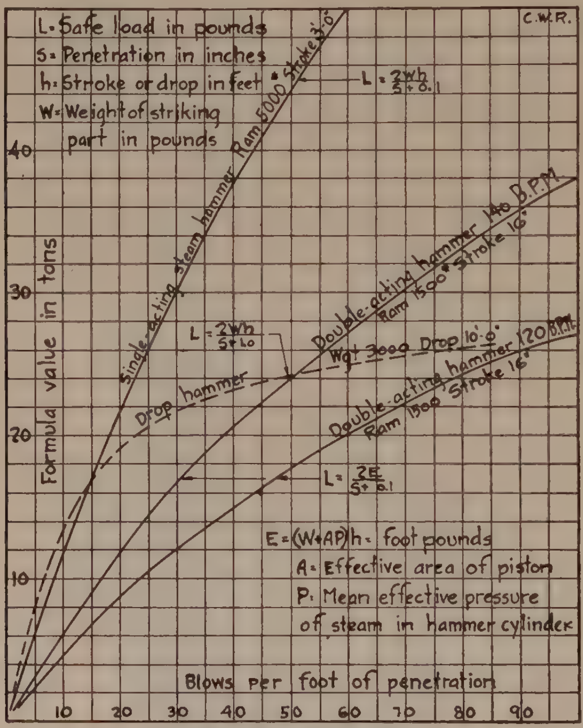
Fig 2.

When this was not done, the plotted curve of formula values from surface of ground to tip of pile was found to be misleading, as one inspector could not keep accurate records of all the data required.

Four pile drivers were used for the foundation piles, two equipped with double-acting and two with single-acting steam hammers. After the foundation driving began, all test piles were driven with a single-acting hammer, the stroke being 3 feet 0 inches, and the weight of ram

5,000 pounds. With this hammer the boundaries of the soil strata were indicated clearly.

With short piles stopped in the sand stratum, the values for the double-acting hammer were about double those for the single-acting hammer. For long piles driven through the sand and 20 feet or more in the clay, there was an even greater difference, the double-acting hammer giving the higher values in all cases. See Fig. 2 for a comparison of formula values for two typical piles driven under the same conditions into the same soils.



Comparison of pile hammer Formula Values

Fig 3

In some areas the sand was very compact and had sufficient depth in which to stop the piles. In trying to get the required embedment in this compact sand, values as high as 70 tons were indicated by the double-acting hammer, while the single acting hammer seldom went over 30 tons. A number of the "high tonnage" piles were pulled and found uninjured, which was sufficient proof that the actual resistance was not as great as that indicated by the double-acting hammer. These piles were long-leaf pine, 20 feet 0 inches long, 11-inch butt, 7-inch tip. No wood pile of this size and kind will stand an actual resistance of much more than thirty tons without injury, and with a drop hammer it will stand less.

Load tests made at the site showed values which agreed fairly well with the values obtained with the single-acting hammer.

Formulas used as pile value indicators are shown with the required notation in Fig. 3. Although no drop hammer was used, a curve is shown for comparison with the other types.

The energy produced by the single-acting hammer was 15,000 foot pounds, while that produced by the double-acting was only 8,000 foot pounds at normal steam pressure, and 4,500 foot pounds at the end of a driving interval. It is possible that a double-acting hammer with a much heavier ram and longer stroke would have been satisfactory. The ram should be two or three times the weight of the pile in order to reduce the loss from impact, or inertia of the pile. On this job, results showed that "$Wh$" (see Fig. 3) is more effective than "$(W+AP)h$."

# HIGHWAY ACCIDENTS

By Clarence P. Taylor *

(Presented at a meeting of the Highway Section of the Boston Society of Civil Engineers, November 22, 1933)

A great deal of hysteria and emotional discussion develop in a contemplation of highway traffic accident problems. This attitude of mind, to a great extent, is fostered by our sincere desire to reduce the accident toll. There is a tendency to exaggerate the relative size of a difficult problem of this nature in the hope that we may frighten ourselves into correcting the difficulties. Exaggeration, overemphasis, hysteria and emotional upsets unquestionably serve to stimulate action and improvement, but they do not provide remedies. These phases of a general discussion of highway accidents never have provided a solution for any traffic accident problem. One very unfortunate thing about exaggeration and overemphasis is that they tend to bias a person's or the public's mind, or to befog issues, so that often the most important things, which should be done first, are overlooked entirely,

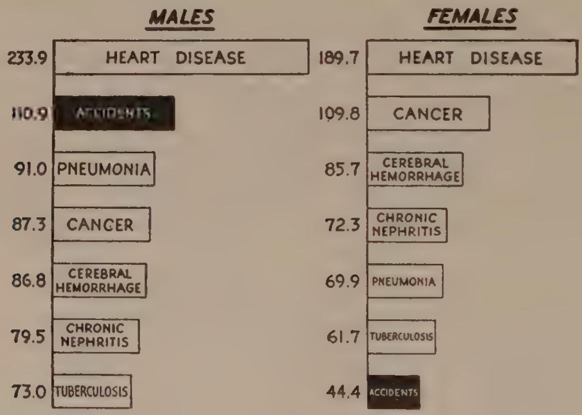


Fig. 1.—Seven Most Important Causes of Death by Sex, 1931

Death rates per 100,000 population

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* Traffic Engineer, Massachusetts Department of Public Works, 100 Nashua Street, Boston, Mass.

Note.—Figs. 1, 2 and 3 used through courtesy of "Accident Facts," 1933 edition, National Safety Council.

or considered as secondary or minor problems to be disposed of with little or no thought. It would be well if a critical and dispassionate analysis were made of the relative seriousness of the traffic accident as compared with other life-taking problems.

## Various Causes of Fatalities

The leading causes of death for the year 1931 are shown in Fig. 1, and these causes are listed separately according to sex. It will be noted that heart disease is the greatest cause of death in both sexes; also that for men accidents (that is, accidents of every description) are the second greatest cause of death, but for women accidental death is least. The reason for this difference in position of accidents as causes of death in the two sexes may be traced to the fact that men suffer by far the greater exposure to the possibility of accidents. Somewhere between one-quarter and one-third of all the accidents listed for men are attributable to motor vehicles; hence, motor vehicles cannot be included among the six leading causes for death.

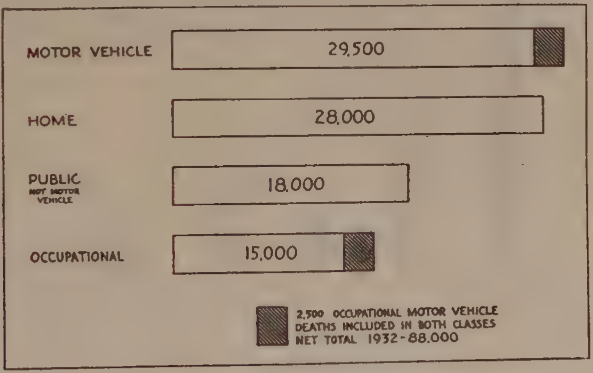


Fig. 2.—Four Principal Classes of Accidental Deaths, 1932

It is interesting to see how fatal motor vehicle accidents as a group compare with other groups of accidents. Consulting Fig. 2, which illustrates the four principal causes for accidental deaths for 1932, the astonishing fact should be noticed that there are nearly as many persons killed in their own homes as there are on streets and highways, although few persons think of the home as a dangerous place. These figures hardly justify spending a disproportionate amount of attention on motor vehicle accidents. Fig. 3 shows two things, — first, the six principal causes of fatalities, and second, the relative change in the accident situation in each group from the year 1913 to 1931. The motor vehicle accidents in the year 1931 obviously outstrip all other forms of accidental deaths. It is known that about one-third of the motor vehicle fatalities occur at intersections. Considering this third of the motor vehicle accidents shown here, it becomes apparent that there are more people killed by accidental falls, not connected with motor vehicles in any way, than in all the accidents at highway intersections in the country. Yet how much more consideration is given to one or two intersections than to the problem of accidental falls.

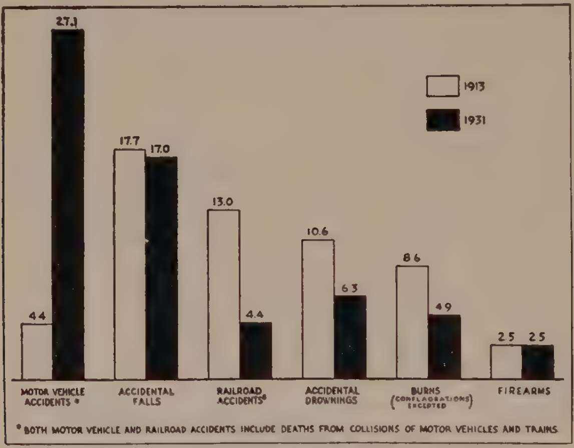


FIG. 3.—FATAL ACCIDENTS IN THE UNITED STATES

Rates per 100,000 population 1913 and 1931

## MOTOR VEHICLE ACCIDENT PROBLEMS

A comparison of accidents in 1913 with those in 1931 reveals a fact that should be borne in mind whenever one despairs of reducing motor vehicle accidents. First, note the enormous increase in motor vehicle accidents from 1913 to 1931; then note the decrease in accidents in each one of the other classes with the exception of firearms, which has remained constant. These statistics should not be taken to mean that these reductions came about of themselves, but it is my opinion that these reductions have been due largely to the enormous amount of intelligent effort and continuous labor which industry has devoted to this complex problem, and that therefore these results give encouragement to the possibility of reducing accidents on highways.

One cannot belittle the highway accident situation in which 29,000 to 34,000 fatalities occur annually in this country alone. What I do want to make clear is that further hysteria over this loss will get us nowhere. We are all convinced of the need for doing something to prevent this toll of accidents, so why not assume a rational outlook upon the problem, and recognize that, while it is bad, it is perhaps not so bad as it could be, nor is it the only major cause of death. Those of us who are closely connected with traffic safety work may take a cue from our brothers in industrial safety by putting in more hours of hard and intelligent labor and spending less effort to scare the public into safety.

Unfortunately, no method has been widely accepted for establishing the efficacy with which any State is dealing with its traffic accident problem. One could readily understand how the total number of fatal accidents in the State would not be a proper measure, because States vary so widely both in population and automobile registration. Besides the factors of population and automobile registration which influence accidents, there are other factors, such as density of population, miles of streets and highways, character of streets and highways, topography and weather conditions. How all these different factors might be weighed and a fair measure of a unit accident rate obtained is, indeed, a problem.

## PROGRESS IN MASSACHUSETTS

It is not necessary, however, that we wait until some mathematical genius figures this out, for we can get an index as to where our State stands with the others in the matter of accident control. Table I shows that on a basis of 100,000 population this State stands nineteenth. On the basis of gasoline consumed, which measures the exposure (being proportional to the number of miles traveled), it stands seventh. In both these cases Massachusetts ranks high among the forty-eight States.

TABLE I. — STANDING OF MASSACHUSETTS AMONG STATES HAVING LOW FATAL TRAFFIC-ACCIDENT RATES FOR THE YEAR 1932

| BASIS OF COMPARISON | Rate | Standing |
|---|---|---|
| Fatal accidents per 10,000,000 gallons of gasoline . . . | 14.8 | 7 |
| Fatal accidents per 100,000 population . . . . . | 18.9 | 19 |

Why Massachusetts has been able to maintain this enviable position, every one has a right to guess. My opinion is that it is because Massachusetts was among the first States to recognize that the automobile is a machine that must be controlled. Massachusetts was the first State to pass speed laws governing the operation of motor vehicles; it was the first State to have a driver's license law; and it was the first State to require drivers to take an examination for operators' licenses. It was the first State to require uniformity in traffic signs, signals and regulations. It was the first State to establish a traffic section in its highway division. It is the first State to deal constructively with the operator who repeatedly gets into accidents or consistently violates driving rules. Massachusetts is the first State to have trained inspectors thoroughly to investigate fatal accidents and file a complete report with recommendations for remedies. Massachusetts leads all States in actively following up all complaints against drivers and in disciplining operators found guilty of negligence. This record is something to be proud of, and in my opinion this is the reason why this Commonwealth has such a comparatively low accident rate. Having made such a good beginning, it is only reasonable to suppose that these features of accident prevention, having been inaugurated, will be followed up with vigor, which sooner or later will result in an even more favorable standing among the States.

Under no circumstances should we deceive ourselves, statistically or otherwise, into believing that we have the best of the accident situation in this State. Neither do we want to go along year in and year out without some knowledge as to whether or not we are succeeding in our efforts to reduce accidents. In order to obtain a rather broad view of progress in this matter, Fig. 4 was prepared. On this chart are graphs showing the relative change from period to period of fatal accidents for the whole State, population, automobile registration, and traffic volume, from the year 1909 up to the last year when this information was obtained. In later years figures for gasoline consumption and for state highway accidents became known, and these are shown plotted in the latter part of the chart. Population and automobile registration exert a great influence on the number of accidents, hence we should expect the curve for fatalities to follow along pretty much parallel with these two graphs. This is true for Massachusetts until the year 1919, after which fatalities follow a much slower rise than did either population or automobile registration. Of course, no one knows exactly why these curves should have diverged and continued along different slopes, but my own feeling is that since 1919 the constructive steps which this State has taken in the control of automobile driving, mentioned previously, have caused this salutary result. The gasoline consumption curve presents a measure of the use of motor vehicles more exactly than does the curve of population or registration, and indicates the exposure of the public to accident, but probably no more so than does the curve representing traffic volume, which is based on actual traffic counts made each third year. It is interesting to note how closely the gasoline consumption curve parallels the curve representing traffic volume. Accidents on state highways have practically paralleled gasoline consumption, except that during the year 1932 there was an increase in accidents on state highways, whereas gasoline consumption dropped off slightly. According to a check of the accidents reported to the Registry of Motor Vehicles for the whole State, the total figures for each year have risen continuously in the same way that state highway accidents have done. The decrease in fatalities in 1932 would lead one to believe that the total of accidents in general has fallen off. There is a possibility that this may be true and that the apparent increase in total accidents is due to an increased interest in reporting them, rather than an actual increase in their numbers. Be all this as it may, the thing all of us are vitally interested in is permanently turning downward the fatality curve and accident rate for the whole State. The Department of Public Works is determined to do what it can toward reversing the trend of accidents on state highways.

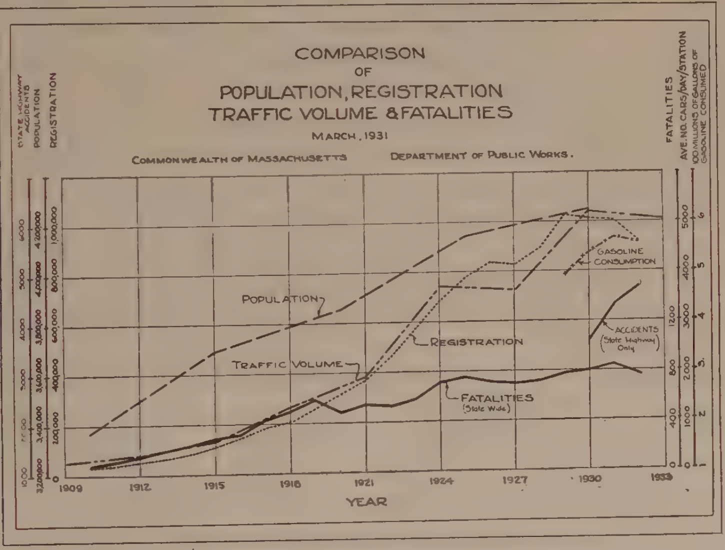


FIG. 4

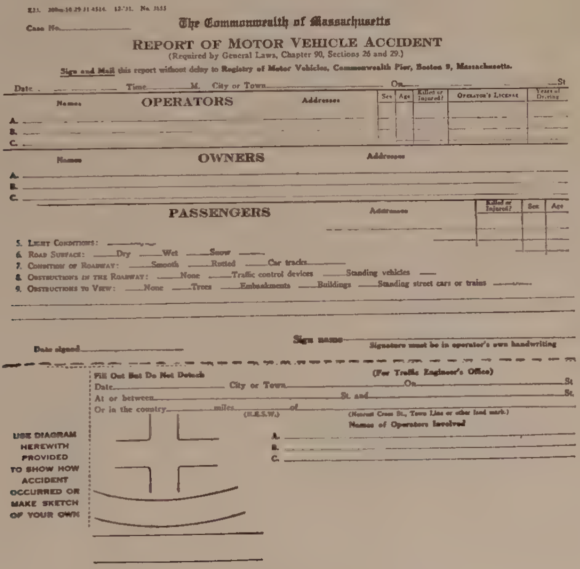
## Traffic-Accident Records of the Department of Public Works

Towards this end the department maintains a traffic section, which has as one of its primary functions the duty of ferreting out from the 35,000 to 40,000 accident reports, which are received annually, information for use in solving practical safety problems. Through the courtesy of the statistician's office of the Registry of Motor Vehicles, the traffic section has been able to receive a complete summary concerning every accident reported to the Registry. These records go back to 1928. Since that time a great deal of pioneering in this field has had to be done. No one ever before had tried to study or classify accidents by location over a whole State, so it took us a long time to develop a system which would present valuable information in such form that it could be readily understood and put to use. The system of filing these 150,000 records had to be changed four times before an efficient means, not only of filing, but of searching, was developed. Last year there was conceived a means of summarizing and cataloguing the information which would give the answer to a large number of questions quickly and with very little labor. It is an entirely different approach to the process of analyzing accidents by statistics than has ever been tried before, and this happens to be the first occasion on which it has been presented publicly.

Before describing this method of analysis it is desirable that the principal steps in its preparation be understood.

No analysis is any better than the source of the information upon which it is based. Moreover, some knowledge as to how the primary data are compiled will help to interpret the conclusions.

Operators, who are involved in traffic accidents in which any one is killed or injured, are required by statute law to furnish to the Registrar of Motor Vehicles a report of that accident upon a form issued by the Registrar. Fig. 5 is a facsimile of such a report. These are obtainable at all police headquarters throughout the State, as well as at all Registry branches and at the main office of the Registry, 100 Nashua Street, Boston. After the driver has filled out this blank he mails it to the Registry, where it is received and a punch card is marked up tentatively by code numbers, summarizing the data which the operator furnished. This code card is then kept in a pending file for a time, until it connects up with the reports sent in by the police department and by other operators, if any. Discrepancies between operators' reports are usually settled by what appears on the police report. As soon as the operator's report is coded on a card, the stub (which appears on the bottom) is detached. These stubs are held until the punch card is received, and all stubs relating to the same accident are fastened together and attached to the same stub. Accumulations of these stubs are sent to the traffic office at frequent intervals to be filed by location. One of the first segregations made is to segregate the accidents which occurred on state highways, because it is an important function of the traffic engineer's office to assemble all information relating to accidents on state highways. The balance of the records are filed by cities and towns, and while no intensive analysis is made of the accidents occurring in cities and towns, special studies are frequently made for particular purposes.



Case No.______

The Commonwealth of Massachusetts

REPORT OF MOTOR VEHICLE ACCIDENT

(Required by General Laws, Chapter 90, Sections 26 and 29.)

**Sign and Mail** this report without delay to **Registry of Motor Vehicles, Commonwealth Pier, Boston 9, Massachusetts.**

Date______ Time______M. City or Town______ On______St

| OPERATORS<br>Names | Addresses | Sex | Age | Killed or Injured? | Operator's License | Years of Driving |
|---|---|---|---|---|---|---|
| A. | | | | | | |
| B. | | | | | | |
| C. | | | | | | |

| OWNERS<br>Names | Addresses |
|---|---|
| A. | |
| B. | |
| C. | |

| PASSENGERS | Addresses | Killed or Injured? | Sex | Age |
|---|---|---|---|---|
| | | | | |

5. Light Conditions: ______
6. Road Surface: ___Dry ___Wet ___Snow ___
7. Condition of Roadway: ___Smooth ___Rutted ___Car tracks______
8. Obstructions in the Roadway: ___None ___Traffic control devices ___Standing vehicles ___
9. Obstructions to View: ___None ___Trees ___Embankments ___Buildings ___Standing street cars or trains ______

Date signed______ Sign name______
Signature must be in operator's own handwriting

Fill Out But Do Not Detach (For Traffic Engineer's Office)

Date______ City or Town______ On______St
At or between______St. and______St.
Or in the country______miles______of______
(N.E.S.W.) (Nearest Cross St., Town Line or other land mark.)

Names of Operators Involved
A.______
B.______
C.______

USE DIAGRAM HEREWITH PROVIDED TO SHOW HOW ACCIDENT OCCURRED OR MAKE SKETCH OF YOUR OWN

FIG. 5

Facsimile of accident report

## ACCIDENTS ON STATE HIGHWAYS

The discussion of highway accidents referred to in this paper relates to state highways only, a fact which should be kept in mind. Moreover, since the facts and information which the traffic section collects frequently are made use of by the project, construction and maintenance engineers of the Department of Public Works, it would be logical to expect that considerable emphasis in the analysis of accidents by the traffic section would rest particularly on their relation to the design, layout, construction and maintenance of the Massachusetts state highway system. This is true. Furthermore, I feel sure that the members of the Boston Society of Civil Engineers would be more interested in these aspects of accident analysis than they would in any others, hence this paper will deal almost exclusively with the solution of the traffic problem from these standpoints.

Besides, the office of the statistician of the Registry of Motor Vehicles turns out a very complete set of accident data summarizing other information, which would help in the administration of the laws governing drivers and automobiles. But these statistics cannot be used for state highway design, construction or maintenance purposes, because they cover the whole State, and because it is next to impossible to break them down to apply to certain roadways or to determine the accident situation at any point or intersection. Hence, it was necessary for the Department of Public Works to set up a separate accident file in which studies of accidents by location can be made.

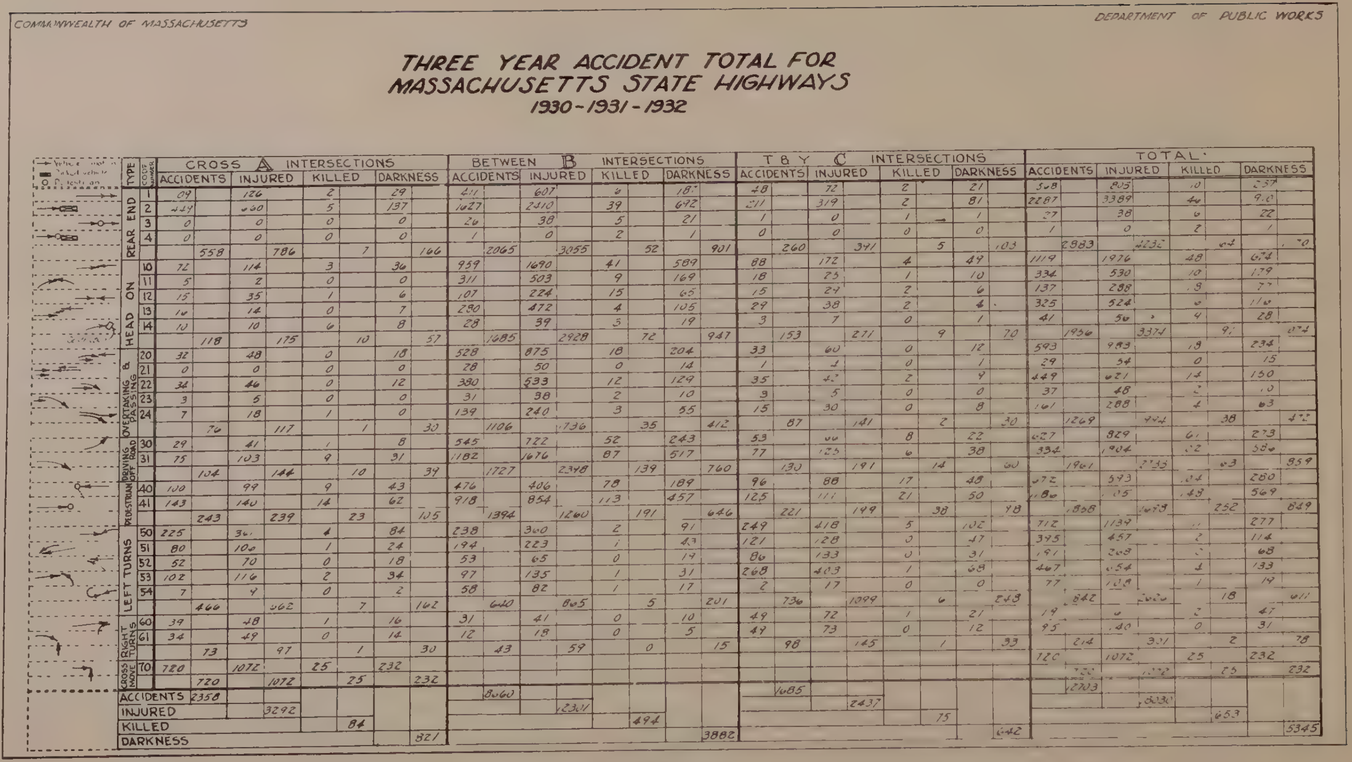
As previously stated, a large proportion of the information contained in the main body of accident reports cannot be utilized for determining highway accident troubles. Moreover, some of it is controversial; that is, one driver's statement may be contradicted by another's. In addition, there are questions which drivers would deliberately lie about or avoid answering correctly. After a year or so of experience with accident records, it was discovered that the thing which could be most depended upon for accuracy, which at the same time revealed more clearly the situation confronting the driver at or during the time of the mishap, was the sketch. That is why the traffic section arranged with the Registrar's office to allow the sketch of the accident to be put upon a detachable tab at the bottom of the report. For disclipinary purposes the sketch means little to the Registry, whereas the body of the report means a great deal. In studying highway accidents, the sketch is all important to the Public Works Department. On operators' reports, 87 per cent furnish good acceptable diagrams. The police are not so faithful in reporting. Only 41 per cent of their reports submitted include the diagram. Of course, we should like to have a sketch of the accident made by the police, because they are better trained in making sketches and in interpreting traffic accidents. However, we are always sure to get one or two good sketches of an accident on the operators' reports.

## CLASSIFICATION OF ACCIDENTS

The whole state highway system has been divided into natural highway links; for example, the Newburyport Turnpike is taken as a whole from Boston to the New Hampshire line. The Worcester Turnpike is considered in two parts, one part being from Boston to Framingham Center, and the other part from Framingham Center to Worcester. Each such link of highway has the record of accidents along it tabulated on an accident record sheet similar to Fig. 6. This chart has three general classifications: cross intersections, between intersections, and T and Y intersections. Under each one of these classifications are tabulated the total number of accidents, vehicles, persons injured, persons killed, and number of accidents occurring in darkness. These main divisions are then broken down into types of accidents, based on the movement involved. Every movement and vehicle combination which is found to occur in these accident records is grouped under headings, such as rear-end, head-on, overtaking and passing, driving off roadway, pedestrian, left turns, right turns, and cross movement. Every accident is put into one or another classification. When the tabulations of accident records by cities and towns on any link of highway are complete for the whole year, a summary for that link is made. Finally, to get the whole accident story for a year, the summaries of all the links are added together and a general bird's-eye view of the accident situation on state highways for the year is obtained. To iron out any irregularities which might appear in a one-year analysis, Fig. 6 has been prepared, summarizing the total of accidents for three years; and this will form the basis of the analysis of highway accidents for the entire State.

## ACCIDENT ANALYSIS

Reviewing the set-up for analysis of highway accidents in a reverse order, we have, first, the summary of accidents for all state highways from which it is possible to draw sweeping and general conclusions affecting all of the roads. Second, we have the section summary or highway-link analysis, which will tell us what is happening on a particular length of highway; also, this separation makes it possible to compare one highway with another, so that by this comparison certain conclusions as to the relative safety or hazard of one class of highway as compared with another may be determined. Next, we have each highway link broken to show accidents which have occurred within the boundaries of each town through which the highway passes. Therefore it would


Vehicle in motion
Parked vehicle
Pedestrian

COMMONWEALTH OF MASSACHUSETTS

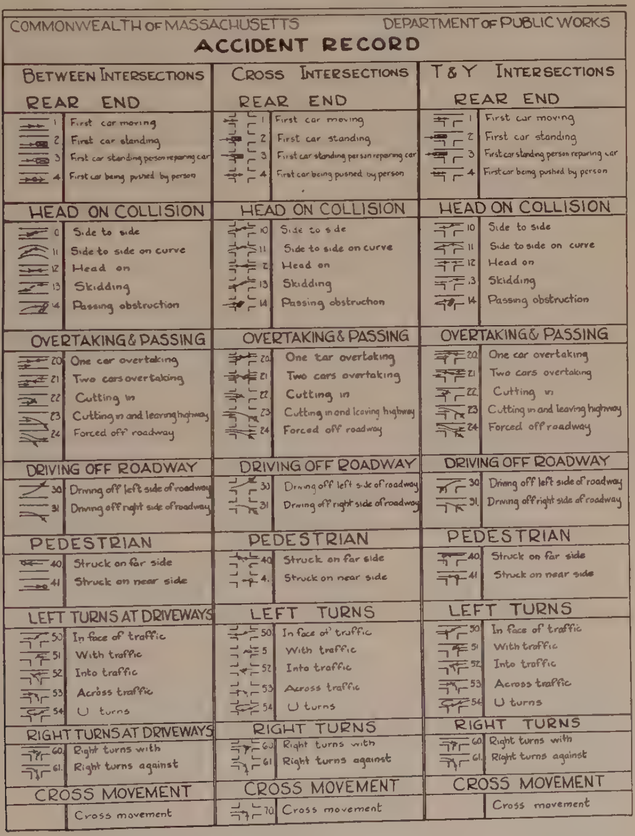
DEPARTMENT OF PUBLIC WORKS

THREE YEAR ACCIDENT TOTAL FOR MASSACHUSETTS STATE HIGHWAYS
1930-1931-1932

| TYPE | CODE NUMBER | CROSS (A) INTERSECTIONS ACCIDENTS | INJURED | KILLED | DARKNESS | BETWEEN (B) INTERSECTIONS ACCIDENTS | INJURED | KILLED | DARKNESS | T & Y (C) INTERSECTIONS ACCIDENTS | INJURED | KILLED | DARKNESS | TOTAL ACCIDENTS | INJURED | KILLED | DARKNESS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| REAR END | 1 | 09 | 126 | 2 | 29 | 411 | 607 | 6 | 187 | 48 | 72 | 2 | 21 | 568 | 805 | 10 | 237 |
|  | 2 | 449 | 660 | 5 | 137 | 1627 | 2410 | 39 | 692 | 211 | 319 | 2 | 81 | 2287 | 3389 | 46 | 910 |
|  | 3 | 0 | 0 | 0 | 0 | 26 | 38 | 5 | 21 | 1 | 0 | 1 | 1 | 27 | 38 | 6 | 22 |
|  | 4 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 1 |
|  |  | 558 | 786 | 7 | 166 | 2065 | 3055 | 52 | 901 | 260 | 391 | 5 | 103 | 2883 | 4232 | 64 | 1170 |
| HEAD ON | 10 | 72 | 114 | 3 | 36 | 959 | 1690 | 41 | 589 | 88 | 172 | 4 | 49 | 1119 | 1976 | 48 | 674 |
|  | 11 | 5 | 2 | 0 | 0 | 311 | 503 | 9 | 169 | 18 | 25 | 1 | 10 | 334 | 530 | 10 | 179 |
|  | 12 | 15 | 35 | 1 | 6 | 107 | 224 | 15 | 65 | 15 | 29 | 2 | 6 | 137 | 288 | 18 | 77 |
|  | 13 | 16 | 14 | 0 | 7 | 290 | 472 | 4 | 105 | 29 | 38 | 2 | 4 | 325 | 524 | 6 | 116 |
|  | 14 | 10 | 10 | 6 | 8 | 28 | 39 | 3 | 19 | 3 | 7 | 0 | 1 | 41 | 56 | 9 | 28 |
|  |  | 118 | 175 | 10 | 57 | 1685 | 2928 | 72 | 947 | 153 | 271 | 9 | 70 | 1956 | 3374 | 91 | 1074 |
| OVERTAKING & PASSING | 20 | 32 | 48 | 0 | 18 | 528 | 875 | 18 | 204 | 33 | 60 | 0 | 12 | 593 | 983 | 18 | 234 |
|  | 21 | 0 | 0 | 0 | 0 | 28 | 50 | 0 | 14 | 1 | 4 | 0 | 1 | 29 | 54 | 0 | 15 |
|  | 22 | 34 | 46 | 0 | 12 | 390 | 533 | 12 | 129 | 35 | 42 | 2 | 9 | 449 | 621 | 14 | 150 |
|  | 23 | 3 | 5 | 0 | 0 | 31 | 38 | 2 | 10 | 3 | 5 | 0 | 0 | 37 | 48 | 2 | 10 |
|  | 24 | 7 | 18 | 1 | 0 | 139 | 240 | 3 | 55 | 15 | 30 | 0 | 8 | 161 | 288 | 4 | 63 |
|  |  | 76 | 117 | 1 | 30 | 1106 | 1736 | 35 | 412 | 87 | 141 | 2 | 30 | 1269 | 1994 | 38 | 472 |
| DRIVING OFF ROAD | 30 | 29 | 41 | 1 | 8 | 545 | 722 | 52 | 243 | 53 | 66 | 8 | 22 | 627 | 829 | 61 | 273 |
|  | 31 | 75 | 103 | 9 | 31 | 1182 | 1676 | 87 | 517 | 77 | 125 | 6 | 38 | 1334 | 1904 | 102 | 586 |
|  |  | 104 | 144 | 10 | 39 | 1727 | 2398 | 139 | 760 | 130 | 191 | 14 | 60 | 1961 | 2733 | 163 | 859 |
| PEDESTRIAN | 40 | 100 | 99 | 9 | 43 | 476 | 406 | 78 | 189 | 96 | 88 | 17 | 48 | 672 | 593 | 104 | 280 |
|  | 41 | 143 | 140 | 14 | 62 | 918 | 854 | 113 | 457 | 125 | 111 | 21 | 50 | 1186 | 1105 | 148 | 569 |
|  |  | 243 | 239 | 23 | 105 | 1394 | 1260 | 191 | 646 | 221 | 199 | 38 | 98 | 1858 | 1698 | 252 | 849 |
| LEFT TURNS | 50 | 225 | 361 | 4 | 84 | 238 | 360 | 2 | 91 | 249 | 418 | 5 | 102 | 712 | 1139 | 11 | 277 |
|  | 51 | 80 | 106 | 1 | 24 | 194 | 223 | 1 | 43 | 121 | 128 | 0 | 47 | 395 | 457 | 2 | 114 |
|  | 52 | 52 | 70 | 0 | 18 | 53 | 65 | 0 | 19 | 86 | 133 | 0 | 31 | 191 | 268 | 0 | 68 |
|  | 53 | 102 | 116 | 2 | 34 | 97 | 135 | 1 | 31 | 268 | 403 | 1 | 68 | 467 | 654 | 4 | 133 |
|  | 54 | 7 | 4 | 0 | 2 | 58 | 82 | 1 | 17 | 2 | 17 | 0 | 0 | 77 | 103 | 1 | 19 |
|  |  | 466 | 662 | 7 | 162 | 640 | 865 | 5 | 201 | 736 | 1099 | 6 | 248 | 1842 | 2620 | 18 | 611 |
| RIGHT TURNS | 60 | 39 | 48 | 1 | 16 | 31 | 41 | 0 | 10 | 49 | 72 | 1 | 21 | 119 | 161 | 2 | 47 |
|  | 61 | 34 | 49 | 0 | 14 | 12 | 18 | 0 | 5 | 49 | 73 | 0 | 12 | 95 | 140 | 0 | 31 |
|  |  | 73 | 97 | 1 | 30 | 43 | 59 | 0 | 15 | 98 | 145 | 1 | 33 | 214 | 301 | 2 | 78 |
| CROSS MOVE | 70 | 720 | 1072 | 25 | 232 |  |  |  |  |  |  |  |  | 720 | 1072 | 25 | 232 |
|  |  | 720 | 1072 | 25 | 232 |  |  |  |  |  |  |  |  | 720 | 1072 | 25 | 232 |
| ACCIDENTS |  | 2358 |  |  |  | 8060 |  |  |  | 1685 |  |  |  | 12703 |  |  |  |
| INJURED |  |  | 3292 |  |  |  | 12301 |  |  |  | 2437 |  |  |  | 18030 |  |  |
| KILLED |  |  |  | 84 |  |  |  | 494 |  |  |  | 75 |  |  |  | 653 |  |
| DARKNESS |  |  |  |  | 821 |  |  |  | 3882 |  |  |  | 642 |  |  |  | 5345 |

FIG. 6

be possible to see very quickly where the greater part of the problem might lie, and, incidentally, what the characteristics of the accidents in a town might be. The next step is an analysis of the accident records themselves, when, as and if more detailed information is obtained, such as the exact location of the various mishaps, or further information which would assist one in eliminating those accidents which have nothing to do with the situation under consideration; for example, if one wanted to study the effect of signals or types of highway construction on accidents, it would be highly desirable to eliminate from the statistics to be compiled all accidents bearing no relation to the problems under consideration.



COMMONWEALTH OF MASSACHUSETTS DEPARTMENT OF PUBLIC WORKS

ACCIDENT RECORD

| BETWEEN INTERSECTIONS | | CROSS INTERSECTIONS | | T & Y INTERSECTIONS | |
|---|---|---|---|---|---|
| REAR END | | REAR END | | REAR END | |
| 1 | First car moving | 1 | First car moving | 1 | First car moving |
| 2 | First car standing | 2 | First car standing | 2 | First car standing |
| 3 | First car standing person repairing car | 3 | First car standing person repairing car | 3 | First car standing person repairing car |
| 4 | First car being pushed by person | 4 | First car being pushed by person | 4 | First car being pushed by person |
| HEAD ON COLLISION | | HEAD ON COLLISION | | HEAD ON COLLISION | |
| 0 | Side to side | 10 | Side to side | 10 | Side to side |
| 11 | Side to side on curve | 11 | Side to side on curve | 11 | Side to side on curve |
| 12 | Head on | 2 | Head on | 12 | Head on |
| 13 | Skidding | 13 | Skidding | .3 | Skidding |
| 14 | Passing obstruction | 14 | Passing obstruction | 14 | Passing obstruction |
| OVERTAKING & PASSING | | OVERTAKING & PASSING | | OVERTAKING & PASSING | |
| 20 | One car overtaking | 20 | One car overtaking | 20 | One car overtaking |
| 21 | Two cars overtaking | 21 | Two cars overtaking | 21 | Two cars overtaking |
| 22 | Cutting in | 22 | Cutting in | 22 | Cutting in |
| 23 | Cutting in and leaving highway | 23 | Cutting in and leaving highway | 23 | Cutting in and leaving highway |
| 24 | Forced off roadway | 24 | Forced off roadway | 24 | Forced off roadway |
| DRIVING OFF ROADWAY | | DRIVING OFF ROADWAY | | DRIVING OFF ROADWAY | |
| 30 | Driving off left side of roadway | 30 | Driving off left side of roadway | 30 | Driving off left side of roadway |
| 31 | Driving off right side of roadway | 31 | Driving off right side of roadway | 31 | Driving off right side of roadway |
| PEDESTRIAN | | PEDESTRIAN | | PEDESTRIAN | |
| 40 | Struck on far side | 40 | Struck on far side | 40 | Struck on far side |
| 41 | Struck on near side | 4. | Struck on near side | 41 | Struck on near side |
| LEFT TURNS AT DRIVEWAYS | | LEFT TURNS | | LEFT TURNS | |
| 50 | In face of traffic | 50 | In face of' traffic | 50 | In face of traffic |
| 51 | With traffic | 5 | With traffic | 51 | With traffic |
| 52 | Into traffic | 52 | Into traffic | 52 | Into traffic |
| 53 | Across traffic | 53 | Across traffic | 53 | Across traffic |
| 54 | U turns | 54 | U turns | 54 | U turns |
| RIGHT TURNS AT DRIVEWAYS | | RIGHT TURNS | | RIGHT TURNS | |
| 60 | Right turns with | 60 | Right turns with | 60 | Right turns with |
| 61 | Right turns against | 61 | Right turns against | 61 | Right turns against |
| CROSS MOVEMENT | | CROSS MOVEMENT | | CROSS MOVEMENT | |
| | Cross movement | 70 | Cross movement | | Cross movement |

FIG. 7.—TYPES OF CONDITIONS INCLUDED IN ACCIDENT RECORDS

Beginning the discussion of Fig. 6, dealing with the three-year total of accidents on state highways, with the question, "Where do most of the accidents occur, at or between intersections?" we find that 68 per cent of the accidents occur between intersections; yet how much more effort and how much more attention have been given to the problem at intersections than to the problem between intersections. It is true, no doubt, that on an average the intersection has more accidents than any other single point along the highways, but it is equally true that the bulk of the highway accident problem relates to the highway between intersections rather than at them. The number of persons killed or injured per accident is the same, so there is no difference in the relative seriousness of the average accident.

The question may have arisen as to why intersections themselves were divided into two classes, namely, cross intersections, and T and Y intersections. The reason for this is that for some time I have had a theory that the T and Y types of intersection (more particularly, the T intersection) have some inherent accident-prevention characteristics; that is, a driver cannot dart across a thoroughfare, because the street terminates or forks. This requires that they drive more slowly, and to my mind it presents to them a condition which they recognize as requiring more than ordinary care. In Table II we have a comparison of accident rates for these two types of intersections. There are 944 of the cross-intersection type, and 4,157 of the T and Y types of intersections. There were 2,358 accidents at the cross intersections, and 1,685 accidents at a T or Y type of intersection. This gives us a figure of 2½ accidents per cross road, against .41 accident per T and Y entering way. Since accidents are known to vary to a large extent with the volume of traffic, and since it may be assumed that a cross street would contribute more accidents than would a T or Y entering way, it would be only fair to take this into consideration. On any basis that this might be figured, the maximum additional traffic which one would expect the cross street to carry could not very well be estimated as beyond twice that of a T or Y intersection; hence, multiplying the accident rate per T and Y intersections by two, we still find that the T or Y intersection would be more than three times as safe a design as a cross intersection would be. The relative seriousness of the accidents is practically the same in both cases.

TABLE II. — COMPARATIVE ACCIDENT RATES FOR CROSS INTERSECTIONS AND T AND Y INTERSECTIONS

| | Type of Intersection | |
|---|---|---|
| | Cross | T and Y |
| Total number along state highways | 944 | 4,157 |
| Total number of accidents, three years (1930 to 1932) | 2,358 | 1,685 |
| Number of accidents per intersection | 2.50 | .41 |

## ACCIDENTS AFTER DARK

A factor in accidents which must be faced squarely is the condition of darkness. The percentage of accidents occurring after dark means very little, unless one knows the amount of travel or exposure after dark. Based on actual traffic counts of vehicle movements over all parts of the State, it is found that 23 per cent of the annual volume of vehicular traffic throughout the state highway system moves during hours of darkness. In the three-year study, 42 per cent of all the accidents occurred after darkness. This should be expected, for it is common knowledge that the human eye cannot see as well in darkness as in daylight.

TABLE III. — RELATION OF DARKNESS AND ACCIDENTS

*Of the Annual Volume of Vehicular Traffic throughout the State, 23 Per Cent moves during Hours of Darkness*

| Type of Accidents | Accidents occurring during Darkness | | |
|---|---|---|---|
| | Total Number | Number per Mile | Per Cent of All Accidents |
| Pedestrian | 849 | .51 | 6.68 |
| Obstruction in road | 28 | .02 | .22 |
| All others | 4,468 | 2.68 | 35.17 |
| Total | 5,345 | 3.21 | 42.07 |

TABLE III. — RELATION OF DARKNESS AND ACCIDENTS — *Concluded*

| LOCATION | DISTRIBUTION OF ACCIDENTS IN DARKNESS | | | |
|---|---|---|---|---|
| | PEDESTRIAN | | ALL OTHERS | |
| | Number | Per Cent | Number | Per Cent |
| At intersections | 203 | 24 | 1,260 | 28 |
| Between intersections | 646 | 76 | 3,236 | 72 |
| Total | 849 | 100 | 4,496 | 100 |

It might be interesting to compare accidents in which pedestrians or obstructions are struck with the other forms of collision. These data are shown on Table III, and indicate that a little less than 7 per cent of all accidents occur to pedestrians during hours of darkness. Collisions with obstructions in the road are an insignificant part of the total. These figures indicate that in all likelihood moving objects are more difficult to see than are those which are more or less stationary. The bulk (76 per cent) of the pedestrians who are struck after dark happens to be somewhere between intersections rather than at intersections. The same holds practically true for all other types of accidents. The problem of accidents after dark primarily is that between intersections rather than at intersections, although caution should be observed in this respect, since it was pointed out before that the intersection is the point along the highway at which the greatest concentration of accidents occurs.

## COLLISIONS

As far as I know, the most disconcerting information which these analyses of highway accidents have revealed is that the type of accident greatest in numbers is the rear-end collision. Nearly 80 per cent of rear-end collisions are with parked or standing vehicles. Nearly 72 per cent of them occurred between intersections, and only about 41 per cent occurred during hours of darkness. Apparently the tail-light or illumination problem is no greater here than for any average run of accidents. Do not these figures call to mind the need for more serious attention on the part of enforcement officers to the matter of getting parked or disabled cars off the highway? And does it not also show the need for more turnouts and parking places along existing highways, and for including in original designs such provisions in the construction of new highways?

Cases of head-on collisions and driving off the roadway constitute the next large division of types of accidents. Comparisons of highways having a center division with those not having such a dividing strip have revealed that the head-on collision and a large portion of the overtaking-and-passing collisions may be eliminated. The driving-off-roadway accidents deserve careful consideration because of their number. It would seem that it is not so important a matter that a car leaves the roadway as it is what the car strikes after it leaves the roadway; in other words, a line of telephone poles or trees close to the traveled edge of the highway is a certain guarantee of serious consequences to those drivers who may leave the highway. It may be possible, too, that some attention could be given to berme design, so that when a car does leave the roadway there will be much less tendency for the car to turn over. A thought which may have some merit is that in locations where there is an obstruction adjacent to the side of the roadway which has brought calamity to drivers or which is liable to do so, it may be desirable to plant a tough or resistant shrub in advance of the object, thereby cushioning or entirely eliminating a severe impact.

## Pedestrian Accidents

Pedestrian accidents form a large portion of the highway accidents, and they result in an exceedingly large proportion of the fatalities. In fact, nearly 29 per cent of the persons killed on highways are pedestrians. The classifications in this division include cases where pedestrians were crossing the roadway and where they were walking along the main highway. Sixty-two per cent of the pedestrian accidents were cases where the pedestrians were walking along the highway. In this analysis no distinction was made as to whether the pedestrian was walking with or was facing traffic. It has always been assumed that it is safer to walk facing approaching traffic than to walk with one's back toward it. However, it is very interesting to note that a recent news release from the Traveler's Insurance Company revealed that its study indicated that it is more dangerous to walk against approaching traffic than to walk with it. In the 1933 analysis sheets, which are yet to be prepared, an attempt will be made to distinguish between pedestrians traveling in these two directions.

## Left-Turn Accidents

It seems rather surprising that left turns should be nearly as great a factor in accidents as pedestrians. By far the greatest number of these left-turn accidents occur when a driver attempts to turn left in the face of approaching traffic. The majority of these accidents occur at intersections, as would be expected, but about 42 per cent occur between intersections — a rather surprising condition. Turning left from an outside lane provides a large proportion of the accidents between intersections. Next in importance to left turns in the face of approaching traffic is the type of left-turn accidents at intersections where drivers enter from the side street, turn left, and are struck by a car on the cross street approaching on the left. U turns result in very few accidents, despite the fact that there is more attention given to this type of movement than to any of the others. From all this it would, therefore, seem perfectly apparent that there is a great need for drivers to understand that clear hand signals must be given, well in advance, and that the left turn should be started from the lane nearest the center line rather than from that nearest the right side of the highway. Sufficient study has not been given to the effect which a center division on a highway might have on these left-turn accidents, to determine exactly what merit center strips might have in this respect. I am confident that they would be of some help, although it is impossible to state definitely how effective they might be.

## Right-Turn Accidents

The fact that right turns are the least troublesome of all the movements is not at all surprising, when it is realized that right turns are what might be termed a more or less weaving movement. With this thought in mind, it might be a clew as to what might be expected when weaving at intersections is substituted for direct crossings or left turns, through the medium of special design.

The cross-movement type of accident, which seems to call forth so much demand on the part of the public for stop signs, traffic control signals, and the like, occupies but a minor place among these classes of accidents.

## Relative Seriousness of Accidents

It may have been noticed that nearly all these analyses have been made on a basis of accidents reported. The reason for this is that generally (though not always) total accidents is a more reliable basis for getting the proper perspective on the relative hazard of any particular problem. First, because the quantity is far greater, and also because it must be recognized that there is an element of truth in the statement that in many of the accidents the fact that some one was not killed was simply good fortune. On the other hand, some weight should be given to the relative seriousness of the different types of movement; that is, the number of persons killed per thousand accidents, or the number of persons killed and injured per accident. Table IV gives both of these rates. Pedestrian accidents, as should be expected, result in the greatest number of deaths per thousand accidents. Driving off the roadway comes second, head-on collisions third, cross-movement accidents fourth, overtaking and passing fifth, rear-end collisions sixth, left and right turning movements almost tie for the last place. As said before, fatalities form a rather unreliable basis for any type of analysis, because the number of them is so small. If the number of persons injured is added to that of those killed, and there is established a rate of persons killed and injured per accident, we find that head-on collisions produce the most serious results, and this is followed by overtaking and passing, cross movement, rear-end collisions, driving off the roadway, left turns, right turns, and pedestrian. Taking both types of rates into consideration, it would seem only fair to class the pedestrian as the most serious sort of accident, because it rates so high in the number of persons killed per thousand accidents. I should place head-on collisions as those next in importance, followed by driving off the roadway, and overtaking and passing on about the same relative plane. Obviously, while rear-end collisions constitute a large proportion of all accidents, as was pointed out before, their seriousness is not as great as these others, — although they are by no means free from dangerous consequences, since in the three years covered 64 persons were killed and 4,032 persons injured in such accidents.

TABLE IV. — NUMBER OF PERSONS KILLED PER THOUSAND ACCIDENTS, AND NUMBER OF PERSONS KILLED AND INJURED PER ACCIDENT

| TYPE OF ACCIDENT | Persons Killed per 1,000 Accidents | Relative Standing | Persons Killed and Injured per Accident | Relative Standing |
|---|---|---|---|---|
| Rear-end | 22.20 | 6 | 1.49 | 4 |
| Head-on | 46.52 | 3 | 1.77 | 1 |
| Overtaking and passing | 29.94 | 5 | 1.60 | 2 |
| Driving off roadway | 83.12 | 2 | 1.48 | 5 |
| Pedestrian | 135.62 | 1 | 1.05 | 8 |
| Left-turns | 9.77 | 7 | 1.44 | 6 |
| Right-turns | 9.35 | 8 | 1.42 | 7 |
| Cross-movement | 34.72 | 4 | 1.52 | 3 |

One notes the difficulty encountered in attempting to weigh the relative seriousness or rank the different classifications of accidents in order of their severity. One way of getting around the difficulty of using three different bases (namely, accidents, injuries, and/or fatalities) is to convert all these factors into a single item of economic loss on a dollar-and-cents basis. In this way each factor may be weighed in accordance with its importance and a total arrived at which would be much easier to understand; for example, Table V shows the method of computing the economic loss for the three years of the accident study. This yields a total of $7,540,455 — a rather staggering sum for a system of highways not quite 1,700 miles long.

TABLE V. — ESTIMATE OF THE ECONOMIC LOSS

| | Number | Loss |
|---|---|---|
| Accidents, at $35 for overhead costs to prevent, control, or deal with accidents . . . . . . . . | 12,703 | $444,605 |
| Vehicles damaged, at $30 to repair each car . . . | 22,520 | 675,600 |
| Persons injured, at $175 for medical attention and time lost | 18,030 | 3,155,250 |
| Persons killed, at $5,000 for average value to community . | 653 | 3,265,000 |
| Total . . . . . . . . . | . . | $7,540,455 |

Table VI converts this figure into unit costs, first, on a basis of the average cost per mile, and second, on a basis of average cost per million vehicle miles.

TABLE VI. — UNIT COSTS

| | |
|---|---|
| Accident cost per mile per three years . . . . | $4,532 |
| Average accident cost per mile per year . . . . | 1,501 |
| Accident cost per million vehicle miles per three years . | 3,125 |
| Average accident cost per million vehicle miles per year | 1,042 |

## BASIS OF COMPARISONS

When comparing the accident rates of two highways, it is very important that they be expressed in units or on the sort of basis on which they can be compared; for example, there is no sense in comparing two highways, one of which is longer than the other, nor two highways of equal length, if the volume of traffic is different. By using a million vehicle miles as a unit, it is possible to make these comparisons. That is one reason why the million-vehicle-miles unit is used in Table VI. This unit gives an average basis for comparing the economic loss on individual highways with that for the whole State. In this way it will not be difficult to select highways which show a favorable accident condition and those which indicate the need for some attention to their accident situation. Later on, when certain intersections are to be analyzed comparatively, a basis of a million vehicles per year will serve identically the same purpose.

TABLE VII. — THREE-YEAR COMPARISON OF STATE HIGHWAY ACCIDENTS WITH TOTAL FOR STATE, 1930, 1931, 1932

| | Number occurring in State | Number occurring on State Highway | Per Cent of Total on State Highway |
|---|---|---|---|
| Accidents reported | 116,788 | 12,703 | 10.88 |
| Persons killed | 2,356 | 653 | 27.72 |
| Persons injured | 140,774 | 18,030 | 12.81 |
| Estimated millions of vehicle miles traveled | 6,800 | 2,448 | 36.00 |

The accident situation on state highways has been discussed at some length. We ought to know what proportion of the accident problem is found on state highways. Table VII shows the distribution of accidents, persons killed, persons injured, and the relative amount of travel for the whole State and for that portion of the State's network of roads which consist of state highways. Table VIII reduces this information to a million-vehicle-mile basis, which is a fair method of comparison. Here it will be seen that whether one considers accidents, persons killed, or persons injured, the state-highway system already enjoys a much more favorable condition than all the highways in the State considered as a whole.

TABLE VIII. — ACCIDENTS PER MILLION VEHICLE MILES

| | Total Million Vehicle Miles | State Highway Million Vehicle Miles |
|---|---|---|
| Estimated millions of vehicle miles traveled | 6,800 | 2,448 |
| Accidents per million vehicle miles | 17.17 | 5.19 |
| Persons killed per million vehicle miles | .35 | .27 |
| Persons injured per million vehicle miles | 20.70 | 7.37 |

# AN EXPLANATION OF THE HARDY CROSS METHOD FOR THE ANALYSIS OF CONTINUOUS FRAMES

By W. W. Bigelow, Member *

(Presented at a meeting of the Designers Section of the Boston Society of Civil Engineers, April 13, 1932)

This paper offers a simple demonstration of the principles involved in the Hardy Cross method of analyzing statically indeterminate structures, so it is based on elementary principles, laying particular emphasis on the physical aspects of the problem.†

The Hardy Cross method considers each portion of a continuous frame between adjacent joints as individual members, at first rigidly fixed at the ends. They are later assumed free to rotate and the structure allowed to approach its natural condition. These changes in fixity in the joints are considered as being controlled by imaginary locking devices. By noting the results as these imaginary devices are systematically locked and unlocked, one is able to ascertain the conditions in the normal structure.

In order actually to see what takes place under these conditions we have made a model of a continuous structure of two members. In order that the two parts may really act (temporarily) as individual members, locking devices have been provided at the joints. The model is shown in Fig. 1 (*a*). It is a continuous beam of homogeneous material with each span of a constant cross section except at the supports, where it is enlarged to form hubs. A bolt passing through each hub converts it into a joint which may rotate. Wing nuts on the bolts provide a means of preventing rotation when desired. Fixed to each hub is a pointer which indicates any rotation of the joint.

First, each joint is locked, and then concentrated loads (in this case equal loads) are applied at the center of each span, after which one joint is unlocked and the changes that take place are noted. That joint is then locked and the process continued through the structure, thus approaching the conditions of the beam simply supported at all three joints. The problem is to discover what the moments will be at the joints under these conditions.

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* Structural Engineer with Jackson & Moreland, Engineers, 31 St. James Avenue, Boston, Mass.

† Professor Cross's article, entitled "Analysis of Continuous Frames by Distributing Fixed End Moments," may be found in the Proceedings of the American Society of Civil Engineers for May, 1930.

As each end of each span is at first fixed, as regards rotation, bending moments are created in the ends of the spans when the loads are applied. These are called "Fixed End Moments," or abbreviated to F. E. M.'s.

The end moments for any beam fixed at the ends and loaded at the center are known to be equal to $\frac{WL}{8}$, where "$W$" represents the magnitude of the concentrated load and "$L$" the length of the span.

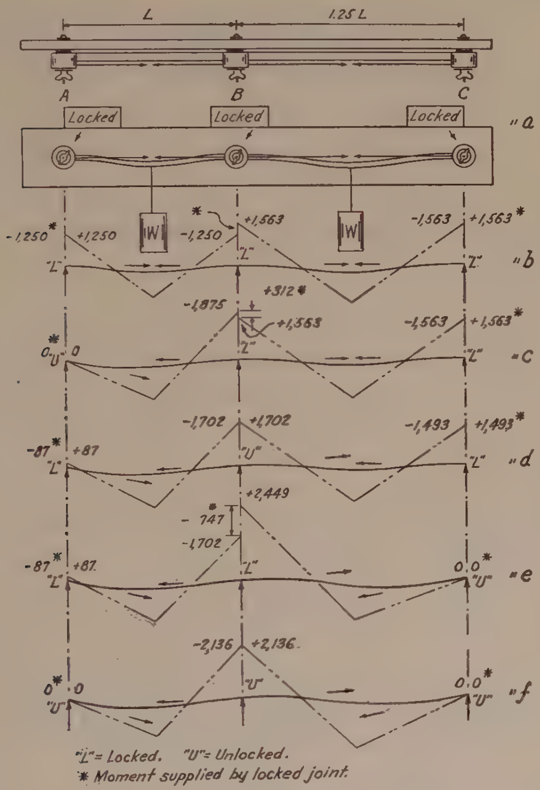

FIG. 1

As the length of the first span of the model is considered equal to $L$ and the second as 1.25 $L$, the above formula gives F. E. M.'s of 0.125 $WL$ for the first span, and 0.1563 $WL$ for the second.

The convention is adopted that a moment which tends to produce clockwise rotation of a joint is a positive moment, and a moment which tends to produce counter-clockwise is negative. This system of designating positive and negative moments is not the one adopted by Professor Cross in his paper. Much may be said on the subject of selecting signs for moments, but this method has, at least, the advantage of making the algebraic sum of the moments at each joint equal to zero for conditions of equilibrium.

In this paper, moment diagrams indicating the magnitude of the moments (but not their signs) will be plotted on the tension side of the member. These are shown in Fig. 1 (*b*) to (*f*).

The story of this beam, now fixed at each support, is recorded by entering the F. E. M.'s on the first line of the table shown in Fig. 2 (*a*). The tabulation of moments will be limited to four decimal places, and for convenience the decimal point and the symbols $W$ and $L$ will be considered as understood and not shown. The F. E. M.'s * with their signs are as follows:

$$F.\ E.\ M._{AB} = +1{,}250$$
$$F.\ E.\ M._{BA} = -1{,}250$$
$$F.\ E.\ M._{BC} = +1{,}563$$
$$F.\ E.\ M._{CB} = -1{,}563$$

The joint at $A$ is then unlocked and the physical resistance to the fixed end moment ($F.\ E.\ M._{AB} = +1{,}250$) is destroyed. As the moment becomes unbalanced the joint rotates and the axis of the beam assumes the position shown in Fig. 1 (*c*).

To record the story of this change the fixed end moment is cancelled by recording on line 2 (marked D. U. M.) in Fig. 2 (*a*), an equal and opposite moment (−1,250). The abbreviation "D. U. M." will be explained later. As the −1,250 is a change in moment it is entered in the column marked by a $\triangle$. A zero is shown on line two of this table under the $\Sigma$ column to record the total moment now existing at $A$.

The rotation of the joint at $A$ also changed the moment conditions throughout the span $AB$ and established a new moment at $B$. $B$ is remembered as being locked and able to take any change in moment.

The total moment at $B$ is now equal to $-\frac{3}{16}WL$, the same as for any beam loaded at the center, freely supported at one end and fixed at the other. The previous moment was equal to $-\frac{1}{8}WL$, and the change in moment is $-\frac{1}{16}WL$. The correcting moment at $A$ was

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* The first letter of the subscripts denotes the end of the span at which the moment exists, and the two letters indicate the span.

$-\frac{1}{8}WL$ (or $-$ 1,250, as shown in Fig. 2 (*a*)). The change in moment at *B* is thus seen to be equal to one-half the correcting moment at *A*. This ratio of one-half holds good for any beam of homogeneous material which has a constant moment of inertia. Half the correcting moment at *A* ($-625$) is entered in the $\triangle$ column at the left of *B*, which, added to the total moment previously existing at this point, gives a figure of $-1{,}875$, as shown under the $\Sigma$ column.

The moment equal to one-half the correcting moment at *A*, which is carried over and added, at the left of *B*, is called a "Carry Over Moment." Such moments are abbreviated to C. O. M.'s.

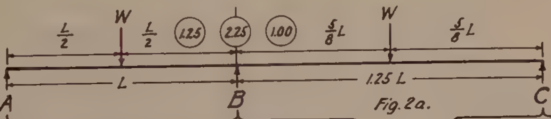


Fig. 2a.

| | | A | | | | | | B | | | | | | C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Step | | Joint | Σ | Δ | | Δ | Σ | Joint | Σ | Δ | | Δ | Σ | Joint |
| 1 | F.E.M. | Locked | +1,250 | | | | -1,250 | Locked | +1,563 | | | | -1,563 | Locked |
| 2 | D.U.M. | Unlock. | 0 | -1,250 | | | | " | | | | | | " |
| 3 | C.O.M. | " | | | | -625 | -1,875 | " | | | | | | " |
| 4 | D.U.M. | Locked | | | | +173 | -1,702 | Unlock. | +1,702 | +139 | | | | " |
| 5 | C.O.M. | " | +87 | +87 | | | | " | | | | +70 | -1,493 | " |
| 6 | D.U.M. | " | | | | | | Locked | | | | +1,493 | 0 | Unlock. |

Fig. 2b.

| | | A | | | | B | | | | | C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Step | | Σ | Δ | | Δ | Σ | Σ | Δ | | Δ | Σ |
| 1 | F.E.M. | +1,250 | | | | -1,250 | +1,563 | | | | -1,563 |
| 2 | D.U.M. | 0 | -1,250 | | -174 | -1,424 | +1,424 | -139 | | +1,563 | 0 |
| 3 | C.O.M. | -87 | -87 | | -625 | -2,049 | +2,206 | +782 | | -70 | -70 |
| 4 | D.U.M. | 0 | +87 | | -87 | -2,136 | +2,136 | -70 | | +70 | 0 |

Fig. 2c.

| | | A | | | | B | | | | | C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Step | | Σ | Δ | | Δ | Σ | Σ | Δ | | Δ | Σ |
| 1 | F.E.M. | 0 | | | | -1875 | +2,345 | | | | 0 |
| 2 | D.U.M. | 0 | | | -261 | -2,136 | +2,136 | -209 | | | 0 |

FIG. 2

The structure itself being in equilibrium, its story thus far complete, we will lock the joint at *A*. The moment at this point remains zero, but the joint is now ready to resist moment.

Joint *B* is still locked, and there is a moment of $-1{,}875$ acting at the left, and $+1{,}563$ at the right, of the joint. The unbalanced moment (acting on the locking device) is equal to the sum of these figures, or $-312$.

This joint is now unlocked. It rotates and the beam assumes the position indicated in Fig. 1 (*d*).

To continue the story. The unbalanced moment which has just been released is distributed to the portions of the member at each side of the joint in proportion to the stiffnesses of the members. The relative stiffnesses of these spans * are directly proportional to the moment of inertia ($I$) of the section and inversely proportional to the length ($L$) of the span. The values of $I$ being the same for each span in the model the stiffness of span $AB$: stiffness of $BC = 1.25 : 1.00$. These figures are shown in Fig. 2 in small circles over their respective spans. The sum of the stiffnesses of the member on each side of joint $B$ is shown in a circle at the joint itself.

After the unbalanced moment has been distributed, each part must be balanced by an equal and opposite moment. This Balancing Moment can be considered as the "Distributed Unbalanced Moment with Sign Reversed" and called by that name or abbreviated to "D. U. M."

The D. U. M. at the left of $B$ equals the unbalanced moment at $B$ (with sign reversed) times the fraction whose numerator is the relative stiffness of the member to the left of $B$ (shown in the circle in span $AB$) and whose denominator is the sum of the relative stiffnesses of the members each side of the joint (shown in circle at $B$).

$$D.\ U.\ M._{BA} = -(-312)\,\frac{1.25}{2.25} = +173$$

and likewise —

$$\begin{aligned} D.\ U.\ M._{BC} = -(-312)\,\frac{1.00}{2.25} &= +139 \\ &\phantom{=}\ +312 \end{aligned}$$

which checks with the total unbalanced moment with sign reversed.

$D.\ U.\ M._{BA}$ and $D.\ U.\ M._{BC}$ are entered on the fourth line of the table in Fig. 2 (*a*) under the $\Delta$'s for $B$. Adding these changes in moment to the previous total moments on each side of the joint we now have a total moment of −1,702 on the left of the joint, and +1,702 on the right. In other words, the joint is balanced.

The structure itself is not yet in equilibrium. As previously seen at $A$ the effect of the change in moment at the joint must be taken account of in the adjacent joints. In other words, from the D. U. M.'s we have to write the corresponding C. O. M.'s before the structure is in equilibrium.

On the fifth line of Fig. 2 (*a*) a C. O. M. of +87 (they are always equal to one-half the D. U. M.'s) is entered in the $\Delta$ column for joint $A$. As already noted, the moment at this joint is zero, but the joint is locked, ready to receive moment, and so adding this gives a total moment of +87. This is indicated in the fifth line under Σ. In a similar manner a C. O. M. of 70 is entered in the △ column for joint *C*. The total moment at this joint becomes −1,493.

---

* The relative stiffness of a member the far end of which is pin supported (and subjected to no moment), and a corresponding member the far end of which is fixed, is in the ratio of ¾ to 1. By the far end is meant the end distant from the applied moment. The ends of the members are assumed as being on unyielding supports.

The structure is now in equilibrium and its story is again complete.

Now, lock *B* and unlock *C*. This condition is illustrated by Fig. 1 (*e*). The unbalanced moment at *C*, just shown in Fig. 2 (*a*), is balanced by a D. U. M. of +1,493, which in turn has a C. O. M. of +747, not shown in the table.

This process of unlocking a joint, applying the D. U. M.'s and C. O. M.'s, then locking the joint and repeating the operations on the next joint could be carried on until the total moments at the joints closely approximate, or equal, the true moments for the normal structure with no locked joints.

Further motion in the model is hardly perceptible when the other two joints are unlocked. The normal condition of the beam is indicated in Fig. 1 (*f*).

The tabulation in Fig. 2 (*a*) does not carry the work through to completion, but was followed thus far that we might better understand the changes that took place by noting them in the order in which they occurred. The practical form of tabulation (giving the same results) is shown in Fig. 2 (*b*).

Assuming all joints in the structure locked, and the F. E. M.'s as before, we will imagine unlocking one joint, completing the D. U. M. step, but holding the C. O. M. step in abeyance. Then after locking the joint and repeating the operations on all the remaining joints the C. O. M. steps will be taken for each joint. This means that the D. U. M. and C. O. M. steps are tabulated in horizontal lines across the table instead of in a zigzag order down the sheet.

In the present example, $D.\ U.\ M._{AB}$ very soon equals $D.\ U.\ M._{BA}$ (each numerically equal to 87), and $D.\ U.\ M._{BC}$ equals $D.\ U.\ M._{CB}$ (each numerically equal to 70). The next step would result in the exchange of equal C. O. M.'s at each side of *B*, and would have no effect on the total moment at that point. This work is therefore terminated.

If this special condition had not been encountered the D. U. M. and C. O. M. steps would have been continued until the C. O. M.'s were negligible. The total moments, instead of equaling, would then closely approximate, the true moments. The work would be terminated after a D. U. M. step, leaving the *joints* in equilibrium.

The work of tabulation can be further reduced, as shown in Fig. 2 (*c*), by observing that it is unnecessary to lock and unlock joints in the structure when the final moments at these points are known to be zero.

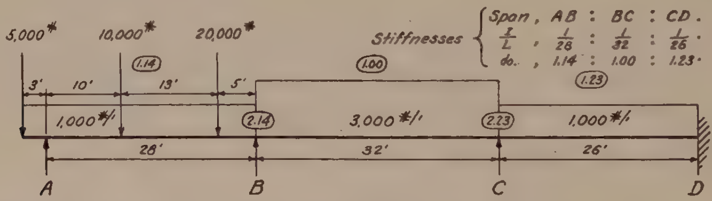
Leaving these joints unlocked does not affect the relative stiffnesses of the two spans, as each is three-quarters as stiff as previously noted. The F. E. M.'s must be selected to meet the conditions of a beam freely supported at one end and fixed at the other. The F. E. M. is, of course, zero at the pinned end, and $\frac{3}{16}$ $WL$ at the fixed support. This gives —

$$F.\ E.\ M._{BA} = -1{,}875$$

and

$$F.\ E.\ M._{BC} = +2{,}345$$

By merely unlocking $B$ and writing the D. U. M. step the final moments at the joint are obtained. These moments are final, as nothing further can be accomplished by carrying over C. O. M.'s to joints which are unable to receive them.



| Step | | Σ | Σ | Δ | | Δ | Σ | Σ | Δ | | Δ | Σ | Σ | Δ | | Δ | Σ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | F. | - 19.5 | +1,214 | | | | -155.8 | +256.0 | | | | -256.0 | + 56.3 | | | | -56.3 |
| 2 | D. | - 19.5 | + 19.5 | -101.9 | | -53.4 | -209.2 | +209.2 | -46.8 | | +89.5 | -166.5 | +166.5 | +110.2 | | 0 | -56.3 |
| 3 | C. | | - 7.2 | - 26.7 | | -50.9 | -260.1 | +253.9 | +44.7 | | -23.4 | -189.9 | +166.5 | 0 | | +55.1 | - 1.2 |
| 4 | D. | | + 19.5 | + 26.7 | | + 3.3 | -256.8 | +256.8 | + 2.9 | | +10.5 | -179.4 | +179.4 | + 12.9 | | 0 | - 1.2 |
| 5 | C. | | + 21.1 | + 1.6 | | + 13.3 | -243.5 | +262.0 | + 5.2 | | + 1.4 | -178.0 | +179.4 | 0 | | + 6.4 | + 5.2 |
| 6 | D. | | + 19.5 | - 1.6 | | - 9.9 | -253.4 | +253.4 | - 8.6 | | - .6 | -178.6 | +178.6 | - .8 | | 0 | +5.2 |
| 7 | C. | | +14.5 | - 5.0 | | - .8 | -254.2 | +253.1 | - .3 | | - 4.3 | -182.9 | +178.6 | 0 | | - .4 | +4.8 |
| 8 | D. | | +19.5 | + 5.0 | | + .6 | -253.6 | +253.6 | + .5 | | + 1.9 | -181.0 | +181.0 | + 2.4 | | 0 | + 4.8 |
| 9 | C. | | +19.8 | + .3 | | + 2.5 | -251.1 | +254.6 | + 1.0 | | + .3 | -180.7 | +181.0 | 0 | | + 1.2 | + 6.0 |
| 10 | D. | | +19.5 | - .3 | | - 1.9 | -253.0 | +253.0 | - 1.6 | | - .1 | -180.8 | +180.8 | - .2 | | 0 | +6.0 |
| 11 | C. | | +18.6 | - .9 | | - .1 | -253.1 | +253.0 | 0 | | - .8 | -181.6 | +180.8 | 0 | | - .1 | +5.9 |
| 12 | D. | -19.5 | +19.5 | + .9 | | + .1 | -253.0 | +253.0 | 0 | | + .4 | -181.2 | +181.2 | + .4 | | 0 | +5.9 |

19.5 252.5* 181.5* 6.4*

* From Three Moment Equation

FIG. 3

## EXAMPLE (FIG. 3)

Given a continuous beam cantilevered at one end, passing over three supports and fixed at the far end. It is assumed that the beam is of homogeneous material and its cross section has a constant moment of inertia. The bending moment at each support is desired.

The relative stiffnesses of the spans are shown in small circles above them with the total of the stiffnesses of two spans shown in a small circle at the support between them.

Imaginary locking devices at each support are considered locked, and the beam loaded as shown. The moment at the left of *A* is due to the loads on the cantilever end of the beam, and is equal to —

$$-(5{,}000\times 3)+(1{,}000\times \frac{3^2}{2})=-19{,}500$$

The F. E. M.'s, due to the uniformly distributed loads, are equal to $\frac{1}{12}$ *WL*, and for the concentrated loads are found from the general rule that "the moment at one end of a fixed ended span due to a concentrated load is equal to the moment which would exist under the load if the beam were simply supported, times the proportional distance of the load from the other end of the span." *

$$F.\,E.\,M._{AB}=+\left[\left(\frac{1{,}000\times 28^2}{12}\right)+\left(\frac{18}{28}\times 10{,}000\times 10\times\frac{18}{28}\right)+\left(\frac{5}{28}\times 20{,}000\times 23\times\frac{5}{28}\right)\right]=+121{,}400$$

$$F.\,E.\,M._{BA}=-\left[\left(\frac{1{,}000\times 28^2}{12}\right)+\left(\frac{18}{28}\times 10{,}000\times 10\times\frac{10}{28}\right)+\left(\frac{5}{28}\times 20{,}000\times 23\times\frac{23}{28}\right)\right]=-155{,}800$$

$$F.\,E.\,M._{BC}=+\frac{3{,}000\times 32^2}{12}=+256{,}000$$

$$F.\,E.\,M._{CB}=-256{,}000$$

$$F.\,E.\,M._{CD}=+\frac{1{,}000\times 26^2}{12}=+56{,}300$$

$$F.\,E.\,M._{DC}=-56{,}300$$

The joint *A* is now considered unlocked. Its D. U. M. is written, the C. O. M. step is held in abeyance and then the joint is considered as locked. The operations are repeated for *B* and *C*. As the fixed joint *D* cannot be unlocked, no balancing operations can be performed on it and it will have no D. U. M. The C. O. M. steps are now taken for all joints, and the D. U. M. and C. O. M. steps are repeated until the C. O. M.'s are very small. The total moments found by the three moment equations are shown below the table. The total moments in the table are seen to be a close approximation of these true moments.

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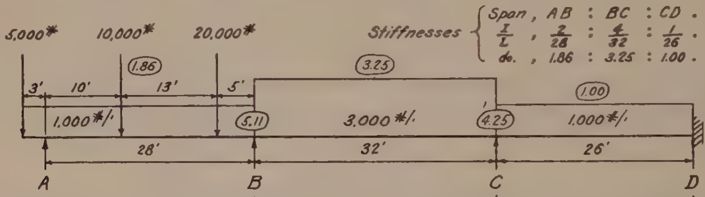
* From "Continuity as a Factor in Reinforced Concrete Design," by Hardy Cross. Proceedings American Concrete Institute, 1925, Vol. 25.

After the first D. U. M. step the total moment at *B* is in error 17.2 per cent as compared with the true moment at this point, and after the second step the error is reduced to 1.7 per cent, and after the third step, to .4 per cent. For all practical purposes this work might have been terminated after the second D. U. M. step.



| Step | | Σ | Σ | Δ | | Δ | Σ | Σ | Δ | | Δ | Σ | Σ | Δ | | Δ | Σ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | F. | - 19.5 | +121.4 | | | | -155.8 | +256.0 | | | | -256.0 | + 56.3 | | | | - 56.3 |
| 2 | D. | | + 19.5 | -101.9 | | - 36.5 | -192.3 | +192.3 | - 63.7 | | +152.5 | -103.5 | +103.5 | + 47.8 | | 0 | - 56.3 |
| 3 | C. | | + 1.2 | - 18.3 | | - 51.0 | -243.3 | +268.6 | - 76.3 | | - 31.9 | -135.4 | +103.5 | 0 | | + 23.6 | - 32.7 |
| 4 | D. | | + 19.5 | + 18.3 | | - 9.2 | -252.5 | +252.5 | - 16.1 | | + 24.4 | -111.0 | +111.0 | + 7.5 | | 0 | - 32.7 |
| 5 | C. | | + 14.9 | - 4.6 | | + 9.2 | -243.3 | +264.7 | + 12.2 | | - 8.1 | -119.1 | +111.0 | 0 | | + 3.8 | - 28.9 |
| 6 | D. | | + 19.5 | + 4.6 | | - 7.8 | -251.1 | +251.1 | - 13.6 | | + 6.2 | -112.9 | +112.9 | + 1.9 | | 0 | - 28.9 |
| 7 | C. | | + 15.6 | - 3.9 | | + 2.3 | -248.8 | +254.2 | + 3.1 | | - 6.8 | -119.7 | +112.9 | 0 | | + 1.0 | - 27.9 |
| 8 | D. | | + 19.5 | + 3.9 | | - 2.0 | -250.8 | +250.8 | - 3.4 | | + 5.2 | -114.3 | +114.5 | + 1.6 | | 0 | - 27.9 |
| 9 | C. | | + 18.5 | - 1.0 | | + 2.0 | -248.8 | +253.4 | + 2.6 | | - 1.9 | -116.2 | +114.5 | 0 | | + .8 | - 27.1 |
| 10 | D. | | + 19.5 | + 1.0 | | - 1.7 | -250.5 | +250.5 | - 2.9 | | + 1.3 | -114.9 | +114.9 | + .4 | | 0 | - 27.1 |
| 11 | C. | | + 18.6 | - .9 | | + .6 | -250.0 | +251.[illegible] | + .7 | | - 1.5 | -116.4 | +114.9 | 0 | | + 0.2 | - 26.7 |
| 12 | D. | | + 19.5 | + .9 | | - .4 | -250.4 | +250.4 | - .8 | | + 1.1 | -115.3 | +115.3 | + .4 | | 0 | - 26.9 |
| 13 | C. | | + 19.3 | - .2 | | + .6 | -249.9 | +251.0 | - .6 | | - .4 | -115.7 | +115.3 | 0 | | + 0.2 | - 26.7 |
| 14 | D. | - 19.5 | + 19.5 | + .2 | | - .4 | -250.3 | +250.3 | - .7 | | + .3 | -115.4 | +115.4 | + .1 | | 0 | - 26.7 |

FIG. 4

## EXAMPLE (FIG. 4)

From the moments found in the previous example it might be considered desirable to vary the moments of inertia for each span. If these are assumed to vary as 2, 4, 1 for the spans from left to right, the relative stiffnesses become 1.86, 3.25, 1.00 and $M_A = 19.5$ as before, $M_B = 250.3$, $M_C = 115.4$ and $M_D$ changes sign and becomes $-26.7$. This example is worked out in Fig. 4.

## FINAL

By means of the model to illustrate the subject, the F. E. M.'s, D. U. M.'s, C. O. M.'s to symbolize the work, and the examples to show the application, it is hoped that this demonstration has been of help in introducing the Hardy Cross Method to those unfamiliar with it.

# A NEW METHOD FOR ANALYZING STRESSES DUE TO LATERAL FORCES IN BUILDING FRAMES

By John B. Wilbur,* Member

(Presented at a meeting of the Designers Section, Boston Society of Civil Engineers, January 10, 1934)

## I. Summary

In this paper an approximate method is presented for the analysis of stresses due to static lateral forces in building frames which derive their resistance to these forces from the continuity of the columns and girders. This method is sufficiently workable and accurate to be proposed as a working method to be used by structural engineers in the design of buildings. For each of the several steps of the method, a working equation is given, so that the application of the method does not require an intimate knowledge of the theory upon which it is based.

To develop these working equations, exact expressions are set up, using the slope deflection relations. To avoid the use of simultaneous equations, assumptions are made. In this way, the resulting expressions are functions of the factors which actually determine the stresses, namely, the external loading, the dimensions of the structures, and the make-ups of the members. Thus the working equations, while easily applied, are rational in form.

## II. Assumptions

In addition to the assumptions underlying the method of slope deflection, the following assumptions are made:

1. The external horizontal loads are concentrated at panel points, and all act in the same direction.

2. Under these loads, all joints rotate in the same direction.

3. The approximations made in order to simplify computations do not affect the results enough to impair their value. For these approximations, see Appendix.

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* Instructor in Civil Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

## III. NOTATION

1. *Main Letters:*

$$\left.\begin{array}{l} K=\dfrac{I}{L} \\ \theta=\text{slope} \\ R=\dfrac{d}{L} \end{array}\right\}\text{as ordinarily used in slope deflection.}$$

$H$ = total horizontal external shear on a story.
$h$ = story height.
$M$ = moment.
$E$ = modulus of elasticity.
$x$ = per cent of story height from mid-story to the average elevation of column inflection points for the story. (Positive when above mid-story.)

2. *Subscripts:*

$c$ = column.
$g$ = girder.
$o$ = story or floor considered.
$a$ = story or floor above the story or floor considered.
$b$ = story or floor below the story or floor considered.

3. *Summation Limits:*

$\Sigma_O^F$ indicates that summation is for entire floor.

$\Sigma_O^S$ indicates that summation is for entire story.

$\Sigma_O^J$ indicates that summation is for entire joint.

$\Sigma_O^G$ indicates that summation is for entire girder.

## IV. DESCRIPTION OF METHOD

1. *General.* — Because this paper is limited to the analysis of stresses in a bent of known make-up due to forces of known magnitude does not mean that the writer overlooks other factors of uncertainty which enter into the problem of wind stress determination viewed as a whole. It implies, rather, that the proper procedure in attempting to reduce the problem as a whole to a satisfactory working basis is to divide it into its component parts and attack it step by step.

A building frame is a highly indeterminate structure. As such it may be defined mathematically as a structure wherein there are more independent components of stress than there are independent relations of statics. But before we can deal rationally with this type of structure it is desirable to have a physical conception of just what a statically indeterminate structure is.

The structures shown in Figs. 1 (*a*) and 1 (*b*) are statically determinate. The moments, shears and direct stresses depend only upon the geometry of the figure and the applied loads. Combined, these two structures become that shown in Fig. 1 (*c*). The load $P$ now has two possible paths which it may follow, *i.e.*, either system (*a*) or system (*b*) is available. If the make-ups of the two columns are about the same, each will take about the same portion of $P$ in shear, and the structure will deflect as shown in Fig. 1 (*d*). If, however, one column is much heavier than the other members, the structure will act as shown in Fig. 1 (*e*), and entirely different stresses result. This is because the structure shown in Fig. 1 (*c*) is statically indeterminate. The stresses are now functions of the make-ups of the members as well as of the geometry of the figure and the magnitude of the applied loads. Since this is so, a correct stress analysis must take into account these make-ups.

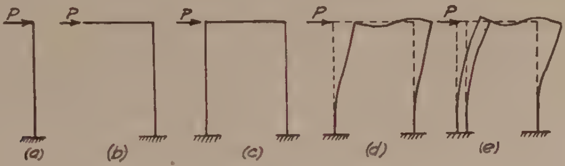


FIG. 1

The present methods of analyzing building frames may be divided into two general groups. The first group includes the methods of least work, slope deflection, and moment distribution. These methods take into account the make-ups of the members and give results often referred to as exact, but they are tedious in their application and require a high development of technique on the part of the computer.

The second group of methods includes the portal method, the cantilever method, variations of these two methods, and a method devised by Prof. H. L. Bowman. These methods either neglect the make-ups of the members or consider their effects very incompletely. While simple in their applications, their results may be greatly in error. The portal method results in equal moments at the ends of all girders of a floor, which at best tend only to represent average values for the floor. The cantilever method tends to increase girder moments toward the center of a building, which is opposite to the actual condition. The Bowman method, while based on assumptions often quite accurate in themselves, is so arranged that cumulative errors pile up in the girder moments.

But whatever may be said against this second group of methods, the facts remain that they have served largely as a basis for design in the past, and that, in general, the buildings designed by their use have been safe, even though the steel used for wind bracing may not have been distributed to its best advantage. It seems questionable, then, whether engineers will desert the approximate methods for the so-called exact methods.

The method presented in this paper lies between the two groups outlined. It is approximate, but gives much more accurate results than the other approximate methods, because it takes into account quite completely the make-ups of the members. While longer in application than other approximate methods, it is believed to be definitely shorter than any of the so-called exact methods.

2. *Typical Derivation.* — While the derivation of the working equations for the proposed method is included in the Appendix to this paper, a typical derivation is given at this point to illustrate the general method of attack used in the development of the new method. For this illustration, the expression for $J$, which may be defined as a relative value of $\theta$ for any joint of a given floor, will be derived.

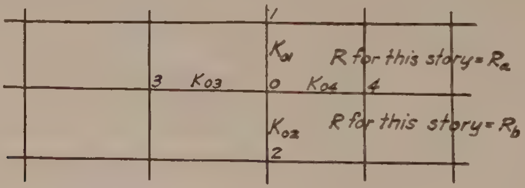


FIG. 2

Referring to Fig. 2, and considering the joint $O$, we may write by statics:

$$M_{01}+M_{02}+M_{03}+M_{04}=O$$

Using the relations of the slope deflection method, we may write:

$$2EK_{01}\,(2\theta_0+\theta_1-3R_a)+2EK_{02}\,(2\theta_0+\theta_2-3R_b)$$
$$+2EK_{03}\,(2\theta_0+\theta_3)+2EK_{04}(2\theta_0+\theta_4)=O$$

Now assume that $\theta_1=\theta_2=\theta_3=\theta_4=\theta_0$ and $R_a=R_b=R_{average}=R_{av}.$

Then

$$K_{01}\,(3\theta_0)+K_{02}\,(3\theta_0)+K_{03}\,(3\theta_0)+K_{04}\,(3\theta_0)= K_{01}\,(3R_{av.})+K_{02}\,(3R_{av.}),$$

or —

$$\theta_0\sum_O^J K=R_{av.}\sum_O^J K_c, \text{ whence } \theta_0=R_{av.}\frac{\sum_O^J K_c}{\sum_O^J K}.$$

But $R_{av.}$ is the same for all joints of a given floor; whence, for that floor, $\theta_n$, the slope at any joint, is proportional to the sum of the *K's* of the columns meeting at the joint divided by the sum of the *K's* of all the members meeting at the joint, or relative $\theta_n=\dfrac{\sum_O^J K_c}{\sum_O^J K}=J_n$ by definition, where $n$ indicates that the expression holds for any joint of the floor.

3. *Outline of Complete Solution.* — We may now outline the procedure for the complete solution. The equations as given are long, because they have been expressed so as to simplify substitution of values. They might have been written in a more compact and attractive form, but in such a form they would be more difficult to apply.

Preliminary to the application of the equations, it is desirable to evaluate $\sum_O^F K_g$ (the sum of the *K's* of the girders for a floor) for each floor; $\sum_O^S K_c$ (the sum of the *K's* of the columns for a story) for each story; and the value of $J$ for each joint.

The procedure may now be summarized by the following four steps (for derivation of equations see Appendix):

Step I: Determine average elevation of the points of inflection of the columns of each story by —

$$x=\frac{\sum_O^S K_{co}}{24\,H_o h_o}\left[\frac{H_a h_a+H_o h_o}{\sum_O^F K_{ga}}-\frac{H_o h_o+H_b h_b}{\sum_O^F K_{gb}}\right] \qquad (1)^*$$

This expression is evaluated once for each story.

---

* In applying this equation to the first story (*i.e.*, the story at which the columns are assumed to be fixed at their base), $K_{gb}$ may be interpreted as the stiffness of the foundations which if taken as infinity causes the second fraction in the bracket to become zero.

Step II: Determine all values of $2E\theta$ by —

$$2E\theta_n = J_n \left[\frac{H_a h_a\,(0.5+x_a)+H_b h_b\,(0.5-x_b)}{3\,\Sigma_O^F (K_{go}\,\Sigma_O^G J)}\right] \qquad (2)$$

The portion of the expression within the bracket is evaluated for each floor.

Step III: Determine all values of $2E\,(3R)$ by —

$$2E\,(3R_o) = \frac{3\,\Sigma_O^S\,[K_{co}\,(2E\theta_a + 2E\theta_b)] + H_o h_o}{2\,\Sigma_O^S K_{co}} \qquad (3)$$

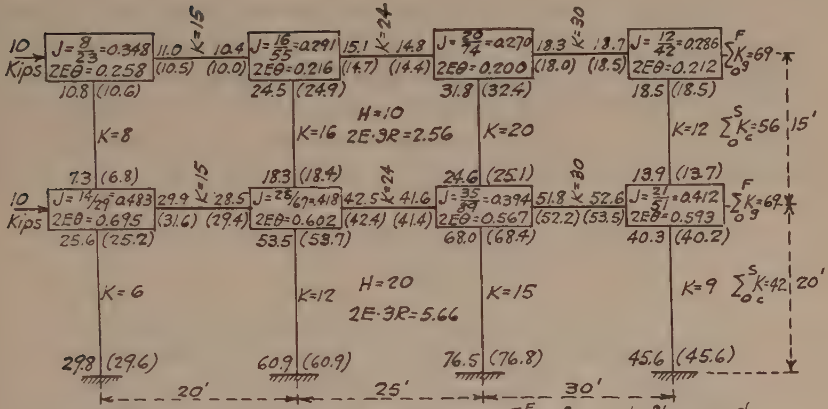
This expression is evaluated once for each story.

Step IV: Determine the values of all moments by —

$$M_{mn} = K_{mn}\,[2(2E\theta_m) + 2E\theta_n - 2E\,(3R)] \qquad (4)$$

For girders, $R=O$. With all moments known, girder and column shears and direct stresses may be computed by statics.

4. *Problem Illustrating Application of Proposed Method.* — Determine the end moments in the columns and girders of the bent shown in Fig. 3. This bent is chosen for an illustrative problem because its non-uniform make-up and lack of symmetry enable it to demonstrate the manner in which the proposed method operates under conditions not altogether favorable to accuracy. Had a symmetrical and more regular bent been chosen for the purpose of illustrating the method, the small amount of labor involved in solution would have been more striking.



Preliminary: Compute values of J for each joint, $\sum_0^F K_g$ for each floor, and $\sum_0^S K_c$ for each story, as shown on sketch

Step I: 2nd Story:

$$x_2 = \frac{56}{24(10)(15)}\left(\frac{10\times15}{69} - \frac{10\times15+20\times20}{69}\right) = -0.090;$$

1st. Story

$$x_1 = \frac{42}{24(20)(20)}\left(\frac{10\times15+20\times20}{69}\right) = +0.035$$

Step II: Roof·

$$\frac{2E\theta_n}{J_n} = \frac{(10)(15)(0.590)}{3\left\{\begin{matrix}15\,(0.639)\\ +24\,(0.561)\\ +30\,(0.556)\end{matrix}\right\}} = 0.741$$

(Note: $2E\theta_n = \frac{2E\theta_n}{J_n} \cdot J_n$)

1st floor

$$\frac{2E\theta_n}{J_n} = \frac{(10)(15)(.410)+(20)(20)(.465)}{3\left\{\begin{matrix}15\,(0.901)\\ +24\,(0.812)\\ +30\,(0.806)\end{matrix}\right\}} = 1.440$$

Step III: 2nd Story

$$2E\cdot3R_2 = \frac{3\left\{\begin{matrix}8\,(0.953)\\ +16\,(0.818)\\ +20\,(0.767)\\ +12\,(0.805)\end{matrix}\right\} + 10\times15}{2\times56} = 2.56$$

, 1st Story

$$2E\cdot3R_1 = \frac{3\left\{\begin{matrix}6\,(0.695)\\ +12\,(0.602)\\ +15\,(0.567)\\ +9\,(0.593)\end{matrix}\right\} + 20\times20}{2\times42} = 5.66$$

Step IV· (Typical cases)

M at base of lower left column = 6 (5.66 − 0.695) = 29.8 kip ft

M at top of lower left column = 6 (5.66 − 2 × 0.695) = 25.6 Kip ft

M at left end of center roof girder = 24 (2 × 0.216 + 0.200) = 15.1 Kip ft

Note: Numbers in parenthesis at ends of all members are moments in Kip. ft. by slope deflection method. Numbers without parenthesis at ends of all members are moments in Kip ft. by proposed method

FIG. 3

A summary of the percentage errors occurring in this bent is given in Fig. 4, on the lower curve. For the purpose of comparison with other methods, curves are also given which show the accuracy of other approximate methods as applied to the same bent. These curves should not be interpreted as illustrating the relative accuracy of these methods as applied to any bent, neither should the bottom curve be considered to represent the accuracy which will be obtained by the proposed method as applied to any bent. They do show, however, a definite capability of the proposed method to take into account the irregularity of the bent considered.

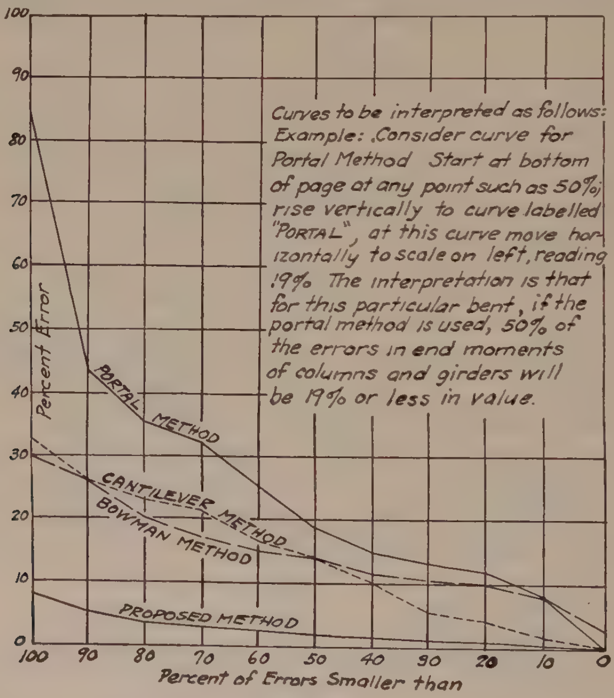


FIG. 4

5. *Extension of Method for Further Accuracy.* — The results obtained by the method as previously outlined may not be as precise as are required in a given case. This would be indicated by lack of static equilibrium of the resulting moments. The method may, however, be readily extended to yield further accuracy, as outlined in the following:

In Step I, equation (*g*) with values of $\Sigma_{O}^{F} M_{ga}$ and $\Sigma_{O}^{F} M_{gb}$ as given by equations (*a*) (see Appendix), is more general than is equation (1). For more accurate values of $x$, proceed as follows: For each story assume points of column inflection to be at mid-story and solve for their more correct value by equation ($g$). On the basis of the results of these solutions, repeat the process, again using equation ($g$); and, for values of $x$ to be used in Step II, use for each story the mean of the two solutions.

Steps II and III may be carried out as before, yielding *preliminary* values of $2E\theta$ and *final* values of $2E\,(3R)$. To obtain *final* values of $2E\theta$, apply at each joint the following equation:

$$\text{Final } 2E\theta = \frac{\Sigma_O^J [K_c\,(2E \cdot 3R)]}{\Sigma_O^J [K\,(2+r)]} \qquad (2a)$$

where $r =$ the ratio $\dfrac{\theta \text{ at far end of a member}}{\theta \text{ at near end of a member}}$, when considering a given joint, and may be obtained on the basis of the preliminary values of $2E\theta$. Equation ($2a$) may be obtained from the second equation in paragraph (2), by letting $\theta_1 = r_1\theta$; $\theta_2 = r_2\theta$; etc.

Moments in the girders may now be obtained from the *final* values of $2E\,(3R)$ and $2E\theta$. As a matter of interest, attention is called to the fact that the successive application of equations ($2a$) and (3) would cause the values of $2E\theta$ and $2E\,(3R)$ to converge to their true values.

The Appendix (pages 54 to 56) shows the development of the basic equations.

# APPENDIX

## APPENDIX: DEVELOPMENT OF BASIC EQUATIONS:

1. Equation for Step I: Because it is desired to locate the average elevation of points of column inflection for each story, this derivation is based upon an "average" bent composed as follows: (1) The K of each girder equals the average K for the girders of the given floor; (2) The K of each column equals the average K for the columns of a given story, (3) The $\theta$s of each joint of a given floor are considered as equal. Referring to Fig. 5 we may write by statics:

$$\sum_0^F M_{ga} = H_a m + H_o n;\ \sum_0^F M_{gb} = H_o p + H_b q \text{ -- (a)}$$

But $\sum_0^F M_{ga} = 2n_a(\text{av.}\,M_{ga})$, where n = number of girders in floor considered, and av. = average. Hence

$$\sum_0^F M_{ga} = 2n_a[2E(\text{av.}\,K_{ga})(3\,\text{av.}\,\theta_a)]$$

$$\left.\begin{aligned} &\text{whence}\quad \text{av.}\,\theta_a = \frac{\sum_0^F M_{ga}}{2E(6n_a\ \text{av.}\,K_{ga})} \\ &\text{and}\quad \text{av.}\,\theta_b = \frac{\sum_0^F M_{gb}}{2E(6n_b\ \text{av.}\,K_{gb})} \end{aligned}\right\}\text{---(b)}$$

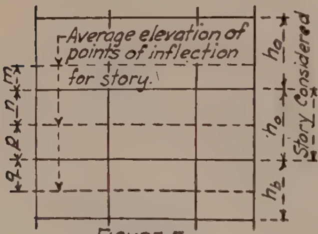


FIGURE 5

For any column of the story considered:

$$M_{TOP} = 2E(\text{av.}\,K_{co})(2\text{av.}\,\theta_a + \text{av.}\,\theta_b - 3R_o)$$

$$M_{BOTTOM} = 2E(\text{av.}\,K_{co})(2\text{av.}\,\theta_b + \text{av.}\,\theta_a - 3R_o),\ \text{whence}$$

$$\Delta M = M_{TOP} - M_{BOTTOM} = 2E(\text{av.}\,K_{co})(\text{av.}\,\theta_a - \text{av.}\,\theta_b) \text{ ----------- (c)}$$

Substituting values of av. $\theta_a$ and av. $\theta_b$ from equations (b),

$$\Delta M = \text{av.}\,K_{co}\left(\frac{\sum_0^F M_{ga}}{6n_a\ \text{av.}\,K_{ga}} - \frac{\sum_0^F M_{gb}}{6n_b\ \text{av.}\,K_{gb}}\right) \text{ ---------------- (d)}$$

By statics, $H_o h_o = 2N_o(\text{av.}\,M_{co})$, where N = number of columns, whence: $\text{av.}\,M_{co} = \dfrac{H_o h_o}{2N_o}$ ----------------------------- (e)

Referring to Fig. 6:

$$2\,\text{av.}\,M_{co} = M_{TOP} + M_{BOTTOM}$$
$$= M_{BOTTOM} - \Delta M + M_{BOTTOM}$$

whence $M_{BOTTOM} = \text{av.}\,M_{co} + \Delta M/2$

and by similar triangles,

$$\frac{\frac{h_o}{2} + x h_o}{h_o} = \frac{M_{BOTTOM}}{M_{BOTTOM} + M_{TOP}},\ \text{or}\ \frac{1}{2} + x = \frac{\text{av.}\,M_{co} + \frac{\Delta M}{2}}{2\,\text{av.}\,M_{co}}$$

$$\text{or}\quad x = \frac{\Delta M}{4\,\text{av.}\,M_{co}} \text{ ---------------- (f)}$$

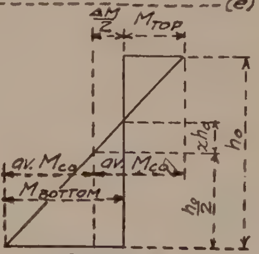


FIGURE 6

Substituting values of $\Delta M$ and av. $M_{co}$ from equations (d) and (e),

$$x = \frac{N_o\ \text{av.}\ K_{co}}{12H_oh_o}\left(\frac{\sum_o^F M_{ga}}{n_a\ \text{av.}\ K_{ga}} - \frac{\sum_o^F M_{gb}}{n_b\ \text{av.}\ K_{gb}}\right)$$

$$= \frac{\sum_o^S K_{co}}{12H_oh_o}\left(\frac{\sum_o^F M_{ga}}{\sum_o^F K_{ga}} - \frac{\sum_o^F M_{gb}}{\sum_o^F K_{gb}}\right) \text{-----------------} (g)$$

or, substituting from equations (1)

$$x = \frac{\sum_o^S K_{co}}{12H_oh_o}\left(\frac{H_a m + H_o n}{\sum_o^F K_{ga}} - \frac{H_o p + H_b q}{\sum_o^F K_{gb}}\right) \text{-----------------} (h)$$

In equation (h), if m, n, p and q are assumed as equal to half their respective story heights,

$$x = \frac{\sum_o^S K_{co}}{24H_oh_o}\left(\frac{H_a h_a + H_o h_o}{\sum_o^F K_{ga}} - \frac{H_o h_o + H_b h_b}{\sum_o^F K_{gb}}\right) \text{-------------} (1)$$

2. Equation for Step II Referring to Fig. 7:

$$\sum_o^F M_{go} = 2EK_{12}(2\theta_1+\theta_2) + 2EK_{12}(2\theta_2+\theta_1) + \ldots$$
$$= 2EK_{12}(3\theta_1+3\theta_2) + 2EK_{23}(3\theta_2+3\theta_3) + \ldots$$

But as developed in the body of this paper, $\theta_n = R_{av.} J_n$ where $R_{av.}$ is a constant for a given floor.

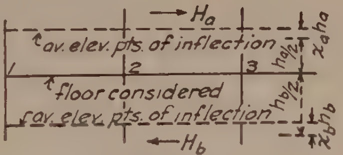


FIGURE 7

$$\therefore \sum_o^F M_{go} = 2E(3)\left[K_{12}(R_{av.}J_1 + R_{av.}J_2) + K_{23}(R_{av.}J_2 + R_{av.}J_3) + \cdots\cdots\right]$$

$= 2E(3R_{av.})\sum_o^F(K_{go}\sum_o^G J)$, wherein $\sum_o^F(K_{go}\sum_o^G J)$ indicates that the K of each girder is to be multiplied by the sum of the values of J at the end of that girder, and the resulting products summed up for the floor

$\therefore 2ER_{av.} = \dfrac{\sum_o^F M_{go}}{3\sum_o^F(K_{go}\sum_o^G J)}$, but $R_{av} = \dfrac{\theta_n}{J_n}$ and $\sum_o^F M_{go} = H_a(0.5+x_a)h_a + H_b(0.5-x_b)h_b$

$$\text{whence } 2E\theta_n = J_n\left[\frac{H_a h_a(0.5+x_a) + H_b h_b(0.5-x_b)}{3\sum_o^F(K_{go}\sum_o^G J)}\right] \text{----} (2)$$

3. Equation for Step III For a given column ab, we may write: $M_{ab} + M_{ba} = 2EK_{ab}(2\theta_a + \theta_b - 3R_{ab}) + 2EK_{ab}(2\theta_b + \theta_a - 3R_{ab})$
$= 2EK_{ab}(3\theta_a + 3\theta_b - 6R_{ab})$

For static equilibrium, the sum of the end column *moments of a story, plus the shear on the story times the story height, equals zero. This may be written as:*

$\sum_0^S 2E[K_{co}(3\theta_a+3\theta_b-6R_o)]+H_oh_o=0$, *where* $\theta_a$ *refers to the slope at the top of any column, and* $\theta_b$ *the slope at the bottom, from which,*

$$\sum_0^S[K_{co}(2E\cdot 3\theta_a+2E\cdot 3\theta_b)]+H_oh_o=2E\cdot 6R_o\sum_0^S K_{co}$$

*or* $$2E\cdot 3R_o=\frac{3\sum_0^S[K_{co}(2E\theta_a+2E\theta_b)+H_oh_o}{2\sum_0^S K_{co}} \quad \text{-----------}(3)$$

*4. Equation for Step IV: The slope deflection relation*

$M_{ab}=2EK_{ab}(2\theta_a+\theta_b-3R)$ *may be rewritten:*

$$M_{ab}=K_{ab}(2E\cdot 2\theta_a+2E\theta_b-2E\ 3R) \quad \text{----------}(4)$$

# OF GENERAL INTEREST

## PROCEEDINGS OF THE SOCIETY

### MINUTES OF MEETINGS

### Boston Society of Civil Engineers

DECEMBER 20, 1933. — A regular meeting of the Boston Society of Civil Engineers was held this evening at the Engineers' Club, and was called to order by the President, Arthur W. Dean, at 7 P.M.

The President announced the death of Benjamin W. Ellis, who had been a member since September 17, 1902, and who died on December 9, 1933.

The Secretary reported the election of the following:

*Grade of Member:* John Benson Wilbur.

*Grade of Student:* Kenneth F. Knowlton.

The President extended a welcome to a number of members of the Boston Society of Architects who had come at his invitation to hear the address of the evening.

The President then introduced the speaker, Mr. Frederick T. Llewellyn, Research Engineer, United States Steel Corporation, who gave a talk on "Steel Framing for Small Residences," illustrated with lantern slides.

An informal question period followed the talk.

Sixty members and guests attended the meeting. Forty-four attended the buffet supper.

Adjourned at 8.50 P.M.

EVERETT N. HUTCHINS, *Secretary.*

JANUARY 24, 1934. — A regular meeting of the Boston Society of Civil Engineers was held this evening at the Engineers Club and was called to order by Vice-President J. B. Babcock, Jr. One hundred and sixty members and guests were present. Previous to the meeting one hundred and four persons attended the buffet supper.

The Secretary announced the election of the following new members:

*Grade of Member:* Warren Francis Baker.

*Grade of Junior:* Gilbert F. Tyler.

*Grade of Student:* Donald G. Ball, Harry F. Bedell, Earl H. Page, Herbert Everett Whittemore.

The Vice-President stated that the next meeting of the Society will be on February 14, 1934, and will be a joint meeting with the Designers Section, and will be held at the Institute of Geographic Explorations, Harvard University, at which time Capt. Alfred W. Stevens will speak on "Methods and Progress of Aerial Photography for Map Making."

The Vice-President called upon L. S. Cowles to speak briefly about the Emergency Campaign for funds and the work of the Emergency Planning and Research Bureau.

Vice-President Babcock announced that this afternoon Gen. Richard K. Hale, Past President of the Society, had been appointed Associate Commissioner of Public Works by His Excellency Governor Joseph B. Ely.

The technical program consisted of several papers dealing with the Cape Cod Canal and the new high-level highway bridges.

Lieut. Peter P. Goerz, United State Corps of Engineers, Rivers and Harbors, District Engineers Office, Boston, spoke on "The Canal and Appurtenances."

Carroll A. Farwell, member of the firm of Fay, Spofford & Thorndike, Consulting Engineers, spoke on the "Design of the Highway Bridges across Cape Cod Canal."

Frank Andrews, Assistant Civil Engineer, Massachusetts Department of Public Works, described the "New Highway Approaches to the Bridges."

Francis L. Sellew, District Waterways Engineer, Massachusetts Department of Public Works, described the "New State Pier at Bourne."

Maps, diagrams and lantern slides were used to illustrate parts of these projects.

A question period followed the presentation of these papers.

The meeting adjourned at 9.20 P.M.

EVERETT N. HUTCHINS, *Secretary.*

## Sanitary Section

FEBRUARY 7, 1934. — A special meeting was held at the Society rooms, Tremont Temple. A committee consisting of Stuart E. Coburn, Francis H. Kingsbury and Harry P. Burden was appointed to present nominees for the various officers of the Section at the annual meeting to be held March 7, 1934.

Dr. Murray P. Horwood, of Massachusetts Institute of Technology, gave an instructive talk, taking as his subject "A Comparative Study of Certain Presumptive Test Media for Bacteriological Water Analysis." He described the comparative tests made with various media in the determination of *B. coli* and *Coli-Aerogenes*, from which the conclusion was drawn that the standard lactose broth media should still be retained. He found the results with brilliant green lactose peptone bile sufficiently promising to warrant further study with this medium.

The paper was discussed by Messrs. E. S. Chase, G. O. Adams and R. S. Weston.

There were sixteen at Patten's for dinner before the meeting, and twenty-four at the meeting.

FRANK L. FLOOD, *Clerk.*

## Designers Section

DECEMBER 13, 1933. — A meeting of the Designers Section of the Boston Society of Civil Engineers was held this evening at the rooms of the Engineering Societies of Boston, and was called to order at 6 P.M. by Chairman F. W. Weaver, who introduced the speaker, Mr. Mark Linenthal, whose subject was "Structural Features of Theatre Design."

Mr. Linenthal discussed the various problems encountered in the structural design of theatres, particularly the back wall of the stage house and the framing of the balcony. Various illustrations of balcony framings were shown and described.

A discussion on vibrations in balconies followed. Mr. Garland described a method by which he had attempted to calculate the vibration period of a balcony. Mr. Reidy discussed two prominent theatre failures.

There were twenty-five members and guests present.

HENRY BRASK, *Clerk.*

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JANUARY 10, 1934. — A regular meeting of the Designers Section of the Boston Society of Civil Engineers was held on Wednesday, January 10, 1934, at 6 P.M. in the rooms of the Engineering Societies of Boston. Chairman F. W. Weaver presided.

The minutes of the previous meeting were read and accepted. It was voted that the Chairman be empowered to appoint a nominating committee of three to nominate officers for the coming year and to report at the annual meeting in March.

Dr. John B. Wilbur of Massachusetts Institute of Technology presented a paper on "A New Method for Analyzing Stresses due to Lateral Forces in Building Frames." The method described by the speaker is a comparatively short approximate method of determining moments and shears in building frames due to wind loads, and one which compares very favorably with other approximate methods in accuracy.

A discussion followed the presentation of the paper, in which several members took part.

There were thirty-nine members and guests present.

Henry Brask, *Clerk.*

## Highway Section

November 22, 1933. — A regular meeting of the Highway Section of the Boston Society of Civil Engineers was called to order at 8 o'clock by Chairman A. E. Kleinert in the Society's rooms, Tremont Temple.

Reading of the minutes of the previous meeting was omitted. The Chairman appointed the following as nominating committee to present nominations for officers for the year 1934–35: Prof. J. B. Babcock, A. B. Edwards and F. T. McAvoy.

Chairman Kleinert then introduced Mr. Clarence P. Taylor, Traffic Engineer, Massachusetts Department of Public Works, who gave an illustrated talk on the subject, "Highway Accidents."

The address was followed by a general discussion of the subject of accidents, particularly those involving pedestrians.

The meeting adjourned at 9.53 P.M.

Attendance, seventy.

Arthur P. Rice, *Clerk.*

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## APPLICATIONS FOR MEMBERSHIP

[January 20, 1934]

The By-Laws provide that the Board of Government shall consider applications for membership with reference to the eligibility of each candidate for admission and shall determine the proper grade of membership to which he is entitled.

The Board must depend largely upon the members of the Society for the information which will enable it to arrive at a just conclusion. Every member is therefore urged to communicate promptly any facts in relation to the personal character or professional reputation and experience of the candidates which will assist the Board in its consideration. Communications relating to applicants are considered by the Board as strictly confidential.

The fact that applicants give the names of certain members as reference does not necessarily mean that such members endorse the candidate.

The Board of Government will not consider applications until the expiration of fifteen (15) days from the date given.

### *For Admission*

Fife, Walter M., Newton Highlands, Mass. (Age 44, b. Peterboro, Ontario.) Education: primary and high school at Peterboro; junior matriculation, 1905; senior matriculation, 1906; entered University of Alberta, 1908; graduated, 1913; graduate study, Massachusetts Institute of Technology, 1920–21, degree S.M. Professional work: rodman, city engineer's office, city of Edmonton, summers of 1909 and 1910; last three months of 1910 season, transitman on land subdivision; summers of 1911, 1912 and 1913, detailer at Dominion Bridge Company, Winnipeg, Man.; instructor, University of Alberta, October, 1913, to February, 1916; summer of 1915, transitman on land subdivision; February, 1916, to August, 1919, Canadian Expeditionary Force. Teaching sessions of 1919–20, 1921–22, instructor at University of Alberta; September, 1922, became assistant professor at Massachusetts Institute of Technology; September, 1928, promoted to associate professor. Refers to *J. B. Babcock, H. K. Barrows, C. B. Breed, Eugene Mirabelli, C. M. Spofford.*

Graves, George Augustus, Newton Upper Falls, Mass. (Age 52, b. Northampton, Mass.) Education: three years Northampton High School; one year Trenton Art School; one year Massachusetts State College. Experience: 1901–03, rodman with E. E. & E. C. Davis, Northampton; 1904–05, with Clapp & Abercrombie, Greenfield, on installation and mapping of fire district in South Deerfield; 1905–08, rodman, transitman and concrete inspector with New York, New Haven & Hartford Railroad; 1908–12, with Long Island Motor Parkway, Inc., Mineola, N. Y., work consisting of constructing 64 miles of roadway, including grade crossing eliminations, surveys, design of line, grades, culverts and bridges, grandstand and lodges; 1912–13, member of firm of Trenton Engineering Company, surveyors and engineers, as engineer at nine institutions on surveying, design and specifications for drives and roads, supervised by State Highway Commission; 1915 (February–May), with Boston & Maine Railroad, valuation work; May, 1915, to date, with Massachusetts Department of Public Works — six years as draftsman and the last twelve years in charge of preliminary plans and estimates on highway work; is now senior civil engineer in Massachusetts Department of Public Works. Refers to *A. B. Appleton, A. W. Dean, E. N. Hutchins, A. E. Kleinert, Jr.*

URBAN, ALEXANDER PAUL. (Age 25, b. Boston, Mass.) Graduate of Northeastern University in 1932. During his four years in college he worked on cooperative basis; in the engineering department of the city of Newton for the last three years; is now employed by the United States Coast and Geodetic Survey. Refers to *H. B. Alvord, R. S. Brown, G. A. A. Morse, W. P. Morse, G. E. Rice.*

## ADDITIONS

### *Member*

JOHN B. WILBUR, 109 Elm Street, Belmont, Mass.

### *Students*

ELLIOT C. FARWELL, 246 Salem Street, Wakefield, Mass.

KENNETH F. KNOWLTON, 11 Roxbury Avenue, Natick, Mass.

Vol. XXI JANUARY, 1934 No. 1

# BOSTON SOCIETY OF CIVIL ENGINEERS

FOUNDED 1848

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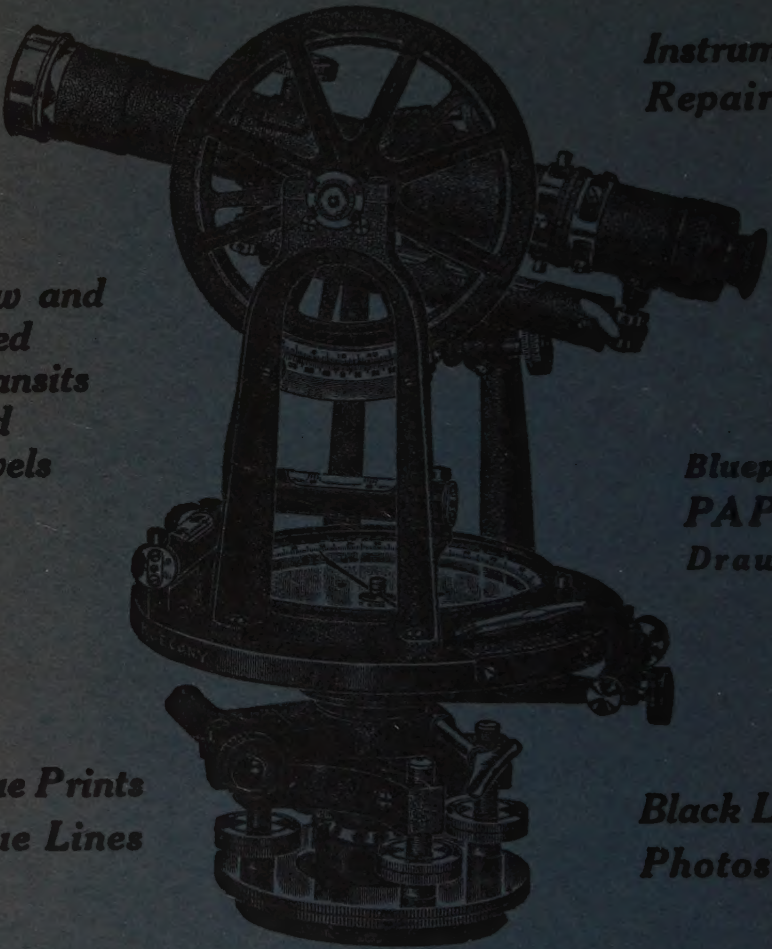

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